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Light Duty Vehicle Road Load Determination

by

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Abstract

When vehicle exhaust emission tests or vehicle fuel consumption measurements are performed on a chassis dynamometer, the dynamometer is usually adjusted to simulate the road experience of the vehicle. Specifically, if the dynamometer measurements are to accurately reflect on-road operation of the vehicle, the dynamometer must supply the appropriate load; that is, the force required to drive the vehicle on a level surface as a function of the vehicle speed. In this study, road load versus speed data were obtained from 64 light duty vehicles. The coast down technique, in which the forces acting on a freely decelerating vehicle are deduced from the speed-time history of the deceleration, was used for all track measurements.

When a vehicle is operated on a chassis dynamometer, the vehicle must overcome the dissipative losses of the drive train and tires before power is transmitted to the dynamometer. Therefore, to derive a dynamometer setting appropriate to simulate the road experience of a vehicle, these losses must be subtracted from the total system losses measured on the track. Measurements of the dissipative forces of the driving tires, the drive train, the non-driving tires, and the non-driving wheel bearings were performed on a 48 inch diameter single roll electric dynamometer.

The dynamometer load settings, resulting from the subtraction of the dissipative losses of the drive train and the driving tires from the total system measurements, are presented. These data are regressed against vehicle mass to develop equations to predict the dynamometer load settings. This equation is then compared with the current light duty vehicle dynamometer adjustment table. The current table is correct, at least within the accuracy of the tire-roll interaction assumptions. It is concluded that while the current table is approximately correct for an average vehicle, significant deviations can exist between any prediction system based on vehicle weight and specific vehicles. It is therefore concluded that further effort should be made to develop road load prediction systems based on vehicle frontal area and, if necessary, estimates of the vehicle aerodynamic drag coefficient.

I. Purpose

The purpose of this study is to develop equations to predict the dynamometer adjustment forces appropriate to simulate the on road performance of light duty vehicles. To accomplish this, equations of road load versus speed were obtained from a diverse class of light duty vehicles. These data were then converted to dynamometer adjustment forces appropriate to simulate the on road experience of a vehicle.

II. Introduction

When vehicle exhaust emission tests or vehicle fuel consumption measurements are performed on a chassis dynamometer, the dynamometer is usually adjusted to simulate the road experience of the vehicle. Specifically the dynamometer must simulate the road load of the vehicle. In this regard the vehicle road load is defined as the component of force in the direction of vehicle motion which is exerted by the road on the vehicle driving wheels. As defined, the road load force is the force which propells the vehicle. In the standard case, when a vehicle is moving with a constant velocity vector on a level surface, this force is equal in magnitude to the sum of the rolling resistance and the aerodynamic drag of the vehicle. Unfortunately, neither this road-tire force, nor the equal magnitude tire-road force can be directly measured because of the virtual impossibility of instrumenting the tire-road interface. Consequently, all experimental methods involve indirect measurements and some corrective process.

Commonly used methods for road-load determination are: the deceleration or coast down technique, drive line force or torque measurements, and manifold pressure measurements. The coast down method was selected as the approach best suited for this study since a method easily adaptable to a diverse class of vehicles was required. The concept of the coast down technique is to determine the rate of deceleration of a freely coasting vehicle; then, knowing the mass of the vehicle, the road-load force may be calculated by Newton's second law, $f = ma$. Previous experimental work at the EPA has demonstrated similar results are obtained with the coast down technique and with drive shaft torque meters.

Sixty-four diverse light duty vehicles were chosen as the experimental sample. These vehicles were chosen to approximately represent the sales weighting of light duty vehicles.

The track measurements include the dissipative losses of the vehicle tires, wheel bearings and drive train. To determine a road value appropriate for adjusting a chassis dynamometer, the dissipative losses from the drive train and driving tires must be subtracted from the total system measurements. These dissipative losses were measured using a 48" diameter roll electric dynamometer.

III. Discussion

This section discusses the specific physical measurements which must be performed to yield the dynamometer adjustment information. This section is included since some of the desired parameters must be determined indirectly; consequently the reason for some of the measurements may not be apparent.

The discussion is presented in three subsections. The system energy section discusses the general aspects of the problem and introduces the concept of equivalent effective mass. The track measurements determine the acceleration of the vehicle system. The mass measurements provide the information necessary to calculate forces or powers from the acceleration measurements.

A. System Energy

The introduction states that the vehicle mass and the vehicle deceleration under freely rolling conditions are the general parameters which must be obtained to determine road-load with the coast down technique. This section will discuss in detail what measurements must be performed to obtain these data.

The total energy of the decelerating vehicle system is the sum of the translational kinetic energy of the vehicle and the rotational kinetic energy of any vehicle components in rotational motion. For all mechanical components of the wheels and drive train, the rotational velocity is proportional to the vehicle velocity; therefore, the energy of the system may be written as:

$$E = 1/2\, mv^2 + 1/2 \left(\sum_i I_i \alpha_i^2\right) v^2 \qquad (1)$$

Where:

E = the total system energy
m = the vehicle mass
v = the vehicle speed
I_i = rotational inertia of the i^{th} rotating component
α_i = the proportionality constant between the rotational velocity of the i^{th} rotating component and the vehicle speed

Differentiating equation (1) with respect to time, and comparing the resulting expression for power with the similar time derivative of a purely translational system, the generalized force on the system may be expressed as:

$$F = \left(m + \sum_i I_i a_i^2 \right) A \qquad (2)$$

Where:

F = the generalized system force
A = the translational acceleration of the system

Defining M as the "total effective mass of the system", where:

$$M = m + \sum_i I_i a_i^2 \qquad (3)$$

Equation (2) now has the familiar form

$$F = MA \qquad (4)$$

The $\sum I_i a_i^2$ term is identified as the "equivalent effective mass" of the rotating components and may be designated by:

$$m_{eq} = \sum I_i a_i^2 \qquad (5)$$

The equivalent effective mass, defined by equations (3) and (5), is simply one approach to include the effect of the rotational kinetic energy of the system. Equations (2) through (4) indicate that the acceleration of the system, the vehicle mass and the equivalent mass of the rotating components are the parameters which must be measured to determine the road load force.

B. Acceleration

Experimentally, it is not practical to measure the vehicle acceleration directly; however, the acceleration may be determined from the vehicle speed. The vehicle acceleration can be calculated by numerically differentiating the velocity versus time data. This is theoretically undesirable for two reasons. The non-analytical differentiation process is inherently noise sensitive and this can be a problem when attempting a least squares fit to the differentiated data. Also, since the acceleration must be derived from the velocity, the initially random errors in the velocity versus time data may not yield normally distributed errors in the acceleration versus velocity. A better approach is to assume a model for the acceleration versus speed equation and then perform analytical operations on this equation to convert it to the form of a speed versus time function. This expression may then be directly fitted to the velocity versus time data to obtain dv/dt as a function of vehicle velocity. The latter approach was chosen. The exact method used is an extension of the approach used by Korst and White[7], and is discussed in detail in reference 2.

C. Mass

The required masses are the gravitational mass and the equivalent effective mass of the rotating components. Equation (5) indicates that

the rotational inertia is the primary measurement necessary to determine the equivalent effective mass of the rotating components:

1) Gravitational Mass

The gravitational mass of the system may be easily measured by a vehicle scale.

2) Effective Equivalent Mass of the Drive Wheels and Drive Train

The effective equivalent mass of the drive wheels and drive train was estimated by the equation:

$$m_{Deq} = 0.0155\ m \qquad (6)$$

where:

m_{Deq} = the effective equivalent mass of the drive train and drive tires

m = the vehicle mass

Equation (6) was developed by regressing the measurements of light duty vehicle drive train and driving tire inertia versus the vehicle mass. The vehicles used were a 50 vehicle subset of the vehicles used in this study. The measurements are described in reference 5. The standard error of this regression was 5.13. Therefore the 68% confidence interval of this regression is approximately ± 5 kg.

3) Effective Mass of the Vehicle Non-Driving Wheels

The effective mass of the vehicle non-driving wheels was estimated by:

$$m_{NDeq} = 1.055 M_t \qquad (7)$$

where

m_{NDeq} = the total effective mass of the two vehicle non-driving wheels and tires

M_t = the mass of one vehicle tire and wheel assembly

The coefficient, 1.055, resulted from regressing rotational inertia measurements of tire-wheel assemblies versus the tire mass. The rotational inertia measurements were made using a three wire torsional pendulum, and are discussed in reference 4. The error of this regression, estimated in the same manner as the error of m_{Deq}, is ± 2.0 kg.

IV. Data Collection

This section discusses the test vehicles, the instrumentation used to collect the data and the test facilities.

Approximately 50 of the vehicles were selected on a sales weighted basis. The percentage of sales in each of the EPA federal test procedure inertia categories was calculated. In each inertia category, when the sales of a single manufacturer was 2% or more of the total U.S. sales, one vehicle of the appropriate type was chosen to represent each 2% of the total sales. The remainder vehicles were chosen to represent unusual vehicles. Specifically, additional very heavy and very light vehicles were chosen. Also, vehicles with reputations of superior aerodynamic designs were added to the fleet, as were several vehicles with "boxy" poor looking aerodynamic designs. The vehicles were procured either by renting or by requesting participation from the automotive manufacturers; 61% were obtained from manufacturers and the remaining 17% were rented. Table I of Appendix A identifies and describes each vehicle.

A. The Track Measurements

The speed versus time data are the only measurements that are required on the test track. Ambient conditions were, however also monitored to allow correction to a set of standard ambient conditions.

1) Test Facility and Test Procedure

All vehicle speed versus time data were collected on the skid pad of the Transportation Research Center of Ohio, in East Liberty, Ohio. This facility is a multilane, concrete, straight track with large turn around loops at each end. Approximately 1 kilometer of this straight track has a constant grade of 0.5% and this section was used for all measurements.

Prior to the coast down measurements, the vehicle tires were adjusted, when cold, to the manufacturers recommended pressures. The cold tire pressures were recorded, as were the tire pressures immediately after the coast down tests. After adjustment of the tire pressures, the vehicles were warmed up for approximately 30 minutes at about 50 mph.

Twenty coast downs were recorded for each vehicle, ten in each direction of travel on the test track. Ten coast downs were conducted by accelerating the vehicle to approximately 65 mph, then shifting into neutral and recording speed versus time as the vehicle freely decelerated. The remaining ten coast downs were conducted in the same manner; however, the initial speed was approximately 40 mph. The two series of coast downs were necessary because the 1 km of section of track with constant grade was insufficient to coast most vehicles from 60 mph to a terminal speed near 10 mph.

2) Velocity Instrumentation

The vehicle speed was measured by a police type Doppler radar. The instrumentation contained a noise discriminator system which rejected the Doppler pulse count any time the period between pulses differed significantly from the previous pulse separation.

Modifications were made to the standard configuration to increase the range. The length of the antenna horn was increased and aluminum

corner reflectors, or strips of aluminum foil, were placed inside the target vehicle windows. These modifications increased the range from about 0.5 km to approximately 1.0 km. The Doppler frequency counter gate time was also increased from approximately 10 msec to 100 msec in an attempt to improve the system precision. This modification did increase the speed resolution; however, it also increased the total period the discriminator evaluated the Doppler signal for extraneous noise. The system noise is basically random; therefore, the probability the discriminator will reject a measurement of the Doppler frequency is linear with the counter gate time. The increase in the precision of each measurement was accompanied by a decrease in the number of speed versus time points measured during the coast down. Also, the range was greatly reduced since the probability of radar signal noise increased as the distance from the transmitter to the target increased. This modification was subsequently rejected and the final configuration of the system provided a range of about 1 km with a resolution of ± 1 mph.

A count of the Doppler frequency was recorded each second during the coast downs on a seven track magnetic digital tape recorder. This recorder and the support electronics were placed in a small van, parked on the track berm. Electric power was provided by an alternator, battery bank, and inverter on this van. An example of the speed versus time record of a light duty vehicle coast down is given in Figure 1.

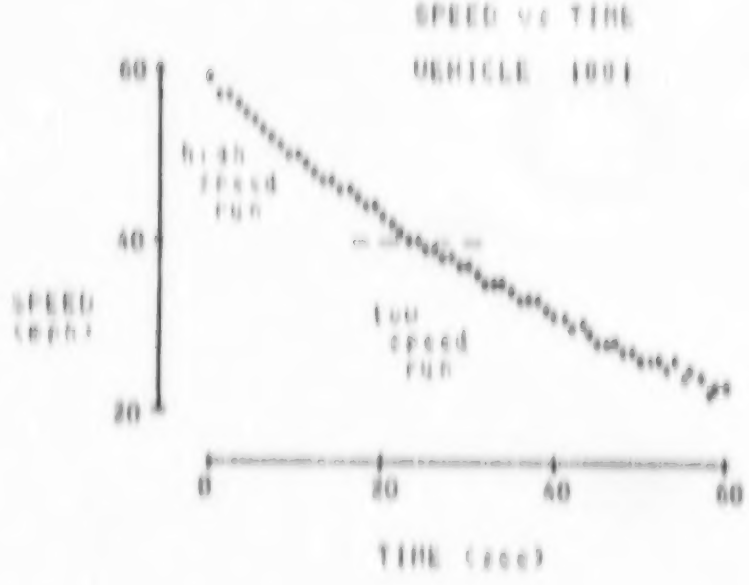


Figure 1

3) Ambient Conditions

Coastdowns were conducted only when steady winds were less than 15 km/hr (9.3 mph) with peak wind speeds less than 20 km/hr (12.5 mph). Wind speed during the test period was measured with a photochopper type six-cup anemometer. The anemometer was located near one side of the test track, at one end of the 1 km test section. These data were recorded at one second intervals on the same magnetic tape as was used to record the vehicle speed. During test periods the ambient temperature was in the range of 5°C (41°F) to 35°C (95°F). The barometric pressure was between 102 kPa (30.2 in Hg) and 94 kPa (27.9 in Hg). The air moisture content ranged from 0.29 to 0.73 gm H$_2$O/gm dry air. These slowly varying ambient parameters were recorded by an observer on a data sheet associated with each vehicle.

B. The Dynamometer Measurements

The dynamometer measurements are conceptually simple since the desired information is force data, and the dynamometer could be used to measure forces directly. The dynamometer used was one of the EPA light duty vehicle electric dynamometers. This dynamometer is a D.C. motor-generator type with a 48" diameter single roll. During these experiments the normal 0-1000 lb. load cell of the dynamometer was replaced with a more sensitive 0-300 lb load cell.

Prior to all measurements the cold tire pressures were adjusted to the manufacturers recommended pressures. Again, the cold pre-test pressures and the hot post-test pressures were recorded. The vehicle weight was adjusted to approximate the vehicle weight during the corresponding track measurement. The dynamometer force measurements were conducted on both the front and rear axles of the vehicle. During the rear axle measurements the transmission was shifted into neutral, as it was during the track coastdowns.

The vehicle was placed on the dynamometer, and then the vehicle and dynamometer were warmed up for 30 minutes at approximately 50 mph. After warm up, the torque necessary to motor the dynamometer and vehicle was measured at speeds from 60 to 10 mph in 5 mph decreasing speed intervals. For each measurement steady state dynamometer speed and torque signals were recorded on a strip chart for a period of approximately 100 seconds. The stabilized values were then read from the strip chart by the dynamometer operator.

After the measurements were completed with the full vehicle weight resting on the dynamometer rolls, the vehicle was then lifted until the vehicle tires were just contacting the dynamometer roll. The vehicle tires were considered to be just touching the dynamometer roll if a person could, with difficulty, manually cause the tire to slip on the roll when the roll was locked. With this test configuration the torque versus speed measurements were repeated as before. Finally, the torque required to motor only the dynamometer was recorded in the same manner.

The dynamometer speed data were converted to the units of m/sec. All torque data were converted to force in newtons at the roll tire interface. A scatter plot of the data from one vehicle, after conversion to force at the tire-roll interface and subtraction of the force necessary to motor the dynamometer, is given as an example in Figures 2(a) and 2(b). In addition, the difference between the force measurement when the full weight of the vehicle was on the dynamometer and the force measurement when the tire was just contacting the dyno roll, is also given in Figures 2(a) and 2(b).

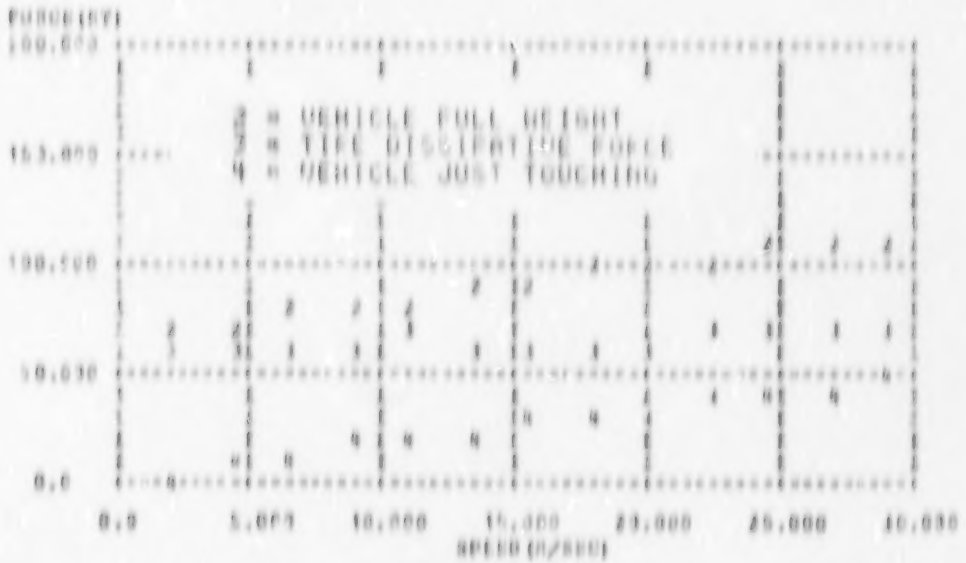


Figure 2 (a)

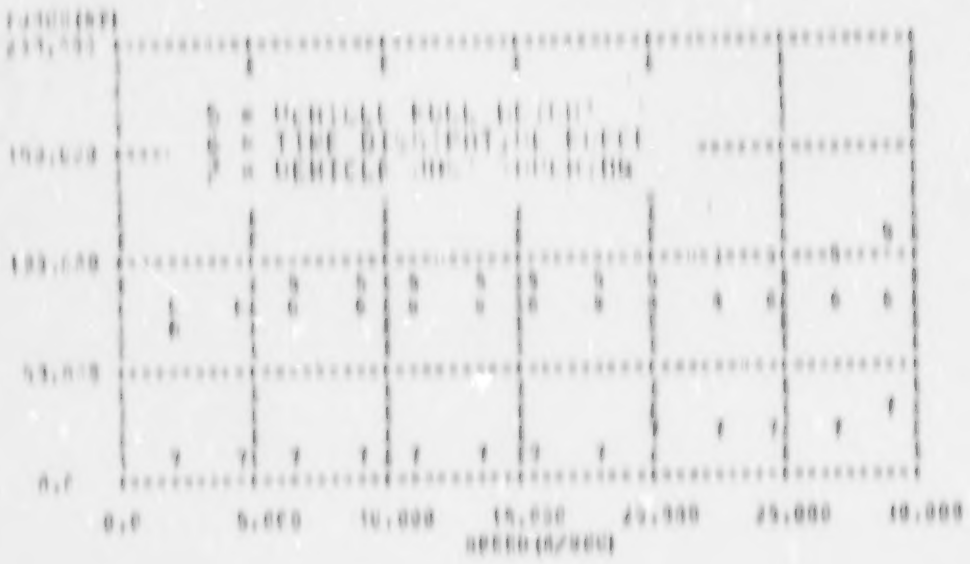


Figure 2 (b)

C. Masses

1) The Gravitational Masses

The gravitational mass was measured by weighing each vehicle, with the driver, immediately after the coast downs. The vehicle scale of the TRC was used for all vehicle mass determinations. TRC personnel indicated calibration checks on this scale have repeatedly been within ± 10 pounds in the 0 to 10,000 pound range.

2) Tire Mass

The tire mass was determined for each vehicle by weighing 4 tires, usually the spare tire, on a platform scale. This scale was a "shipping clerks" scale with a maximum capacity of 1000 lb, and a resolution of ± 0.5 lb.

V. Data Analysis

A. Track Data

The usual form of a vehicle deceleration curve is assumed to be a constant plus a term proportional to the velocity squared. However the effect of a steady head-tail wind will appear as a linear-term. Also, the drive train losses were suspected to be approximately linear in velocity and some published tire data[1] have indicated the inclusion of a linear term may be theoretically desirable. For these reasons, a model equation was chosen of the form:

$$dv/dt = a_0 + a_1 v + a_2 v^2 \qquad (8)$$

Terms were added to equation (8) to account for any effects of wind and track grade. The variables of the resulting equation can be separated and integrated to yield an expression for time as a function of velocity. Since these functions are inverse trigonometric or hyperbolic functions, their inverse may be taken to yield velocity as a function of time. These functions were fitted to the coast down data by the method of least squares to determine the a_0, a_1, and a_2 of equation (8). The mathematics of this technique is discussed in detail in Reference 2 and in the EPA recommended practice for road load determination.

Since the a_2 coefficient multiplies the v^2 it was assumed to represent the aerodynamic drag of the vehicle. The aerodynamic drag is proportional to the air density; therefore all a_2 coefficients were corrected for differences between the ambient conditions during the test, and a set of standard ambient conditions chosen to be:

temperature	20°C (68°F)
barometric pressure	98 kPa (29.02 in Hg)
humidity	10 gm H_2O/kg dry air (70 gr H_2O dry air)

The corrected acceleration coefficients a_0, a_1, and a_2 of equation 8 are presented in table 1 of Appendix B for all vehicles tested. The vehicle tire pressures for the track measurements are give in table 2 of Appendix B.

B. Dynamometer Data

The dynamometer measurements determine the dissipative losses of the driving tires and the drive train. The dynamometer measurements are conceptually simple since the dynamometer used, a 48" roll GE electric chassis dynamometer, measures the forces directly. The only arithmetic necessary is to convert from the force values at the dynamometer load cell to the force at the tire-roll interface. This conversion is simply the ratio of the length of the moment arms. In addition a conversion to MKS units of force was made at this time.

The data for the tire dissipative losses, the wheel bearing losses, and the drive train dissipative losses were all scatterplotted versus speed. These plots indicate the wheel bearing and drive train losses are generally linear with speed, while the tire losses are approximately constant with speed. Consequently a linear least squares regression was fitted to each data set of the drive train and driving tire losses, the driving tire losses, the drive train losses and the non-driving tire losses. The coefficients from these regression analyses are given in Tables 1 through 4 respectively of Appendix C.

The vehicle tire pressures for the dynamometer measurements are given in Table 5 of Appendix C.

C. The total Effective Equivalent Mass of the Vehicle

The total effective mass of the vehicle is the sum of the gravitational mass and the equivalent effective masses of drive train, driving wheels, and non-driving wheels. These masses are given in Table 1 of Appendix B for each vehicle. The total vehicle effective mass is also given in this table.

VI. Results

The total vehicle road load is given by equation (4) as the product of the acceleration and the total system effective mass. The vehicle acceleration is known in the form of the acceleration coefficients of equation 8. Therefore, it is convenient to express the forces in terms of force coefficients where each force coefficient is the product of the total system effective mass and the corresponding acceleration coefficient. That is, for example, the force coefficient, f_D, is given by $f_D = a_D m_T$. These force coefficients were calculated for all vehicles and are presented in Table 1 of Appendix E. Also presented in Table 1 of Appendix E is the total road load force and power at 50 mph.

The total vehicle road load force is the sum of the tire rolling resistances, the dissipative losses of the drive train, wheel bearings, and brake drag, and the aerodynamic drag of the vehicle.

$$F_{TOT} = f_{tire} + f_{mech} + f_{aero} \qquad (9)$$

where

F_{TOT} = the total vehicle road load force

f_{tire} = the sum of the tire rolling resistances

f_{mech} = the mechanical dissipative losses

f_{aero} = the aerodynamic drag

The total vehicle road load force includes the dissipation in the drive train from the rear wheel up to the point where the drive train is decoupled from the engine. When the vehicle is being tested on a dynamometer, the vehicle engine is required to overcome the drive train and

driving tire losses prior to supplying power to the dynamometer. Consequently these losses should not be included in the dynamometer adjustment force. The drive train losses are independent of the choice of a dynamometer, however, the tire rolling resistance will depend on the type of dynamometer. Therefore, to develop the appropriate dynamometer adjustment force, tire losses for that particular dynamometer must be subtracted from the total road measurements, in addition to the drive train losses.

A. Force Coefficients for Road Simulation on a Small Twin Roll Dynamometer

In order to calculate a force appropriate for adjusting a small twin roll dynamometer two assumptions must be made about tire power dissipation on a small twin roll dynamometer.

Assumption 1: "Two on the rolls equals four on the road"

It is commonly stated that two tires dissipate as much energy on a small twin roll dynamometer as four tires dissipate on a flat surface. However, measurements on sufficiently large tire samples to prove or disprove this concept have not yet been reported in the literature. There is some theoretical basis for this statement[7], and one study[8] reported a bias ply tire dissipated very nearly twice as much power on a small twin roll dynamometer as it dissipated on a flat surface. This was observed at inflation pressures of both 25 and 45 psi.

Assumption 2: "Power dissipation on a large single roll is proportional to road power dissipation.

The assumption that tire power dissipation on a large single roll dynamometer is greater than, but proportional to, the power dissipation a flat surface is much better documented. The relationship between tire losses on a large single roll and a flat surface, when determined by torque or power consumption measurements, has been shown theoretically to be given by:

$$F_R = F_D / \sqrt{1 + \frac{r}{R}} \qquad (10)$$

where

F_R = the rolling resistance of the tire on a flat road surface

F_D = the rolling resistance of the tire on a cylindrical dynamometer surface

r = the rolling radius of the tire

R = the radius of the dynamometer roll

The relationship given by equation (10) has been empirically tested by an SAE round-robin tire test program[9]. In addition, the theoretical treatise used to develop equation (10) has also been used to predict the relationship between tire rolling resistances on a large single roll and on a flat surface when the measurements are obtained directly from spindle force transducers. This relationship has been experimentally tested and appears reasonably valid.[10]

The rolling radii of the tires were determined by measuring the hight of the loaded tire, from the contact patch to the top of the tread and dividing by two. Previous experiments at the EPA have shown this technique is a very good simple static measurement of the dynamic rolling radius. Five to ten tires of each tire size were measured and the average rolling radius used for all tires of that size. These average rolling radii are given in Figure 3.

Rolling Radii versus Tire Size

Nominal Tire Size	Average Rolling Radii
13 inches	0.28 m
14 inches	0.31 m
15 inches	0.34 m

Figure 3

The rolling radii given in Figure 3 were inserted into equation (10). The correction factor, r_{ff}/R ranged from 0.836 to 0.801. Since this value was very nearly constant the value 0.811 was used to convert the rolling resistance measurements for all front and rear tires to estimates of the tire rolling resistance on a flat road. In addition, since the tires of light duty vehicles are usually inflated to 45 psi when the vehicle is operated on a small twin roll dynamometer, a correction factor was applied to estimate the flat surface rolling resistance of the tires at 45 psi. The correction factors used were 0.73 for bias ply tires and 0.81 for radial ply tires. [9]These correction factors were derived from the SAE round robin data". These data are from numerous measurements by five different tire testing laboratories, however the test sample was only five tires from a single manufacturer. The estimates of the tire rolling resistances, at 45 psi inflation pressure, of both the driving and non-driving tires, were subtracted from the total road forces as required by assumption 1. In addition, the drive train losses were also subtracted. The resulting coefficients are given in Table 7 of Appendix E as are the force and horsepower at 50 mph.

A significant purpose of this study is to develop equations to predict the appropriate dynamometer power absorber setting as a function of some easily measured vehicle parameter. The ability to predict the small twin roll dynamometer power absorber setting at 50 mph as a function of vehicle weight will be discussed in the following sections.

A theoretically based model can be developed based on several logical assumptions. The first assumption is that, because of similarities in manufacturing technology, the density of light duty vehicles is approximately constant. Stated as an equation, the assumption is:

$$M \propto V \qquad (11)$$

where

M = the mass of the vehicle

V = the volume of the vehicle

The vehicle volume is approximately equal to the product of the three major dimensions. The second assumption is that each of the major vehicle dimensions may be expected to increase approximately equally with an increase in mass. Consequently each major dimension is proportional to the cube root of the vehicle mass. That is:

$$L \propto M^{1/3} \qquad (12)$$

where

L = any of the major vehicle dimensions of height width and length.

The twin roll dynamometer power absorber setting is primarily the aerodynamic drag of the vehicle. The aerodynamic drag is proportional to the frontal area which is approximately equal to the product of the vehicle height and width. Consequently the twin roll dynamometer force adjustment should be proportional to the mass of the vehicle to the two-thirds power.

$$F \propto M^{2/3} \qquad (13)$$

The previous arguments are hardly rigorous, therefore a model of the form:

$$F = aM^{s} \qquad (14)$$

was chosen which allowed the exponent to vary. This model will predict a dynamometer force setting of zero for a vehicle of zero mass, which is theoretically appropriate. Also, if s is less than 1, the model predicts the slope of the force versus mass curve will decrease as the mass increases. This is also theoretically logical and consistent with the observed data.

The model, equation (14), unfortunately cannot be conveniently fitted to the data by least squares process. The fitting process is difficult since the normal equations resulting from the least squares criterion are non-linear. These equations can be solved simultaneously by numerical methods, however a simpler approach is to "linearize"

equation (14) by the following logarithimic transformation:

$$\begin{aligned} \ln F &= \ln a M^s \\ &= \ln c + \ln M^s \\ &= \ln a + s \ln M \end{aligned} \qquad (15)$$

Identifying ln F as the dependent variable and ln M as the independent variable, equation (15) can now be fitted by a stnple linear regression. The results of this regression are:

Regression of Twin Roll Dynamometer Force at 50 mph
versus
Vehicle Mass
Regression model ln F = ln a + s ln M

ln F = the natural logarithm of the dynamometer force (nt) setting at 50 mph

ln M = the natural logarithm of the vehicle mass (kg)

ln a = 2.394

s = 0.479

Sample size 68

Converting to the form of the original model, the prediction equation is:

$$F = 11.0\, M^{0.479} \qquad (16)$$

The statistics of this regression cannot be readily interpreted since they are the statistics of the regression performed on the transformed parameters. In order to evaluate the prediction equation it is plotted, together with the data points, in figure 5. The fitted model is a reasonable appearing choice for these data. There is however a data scatter of approximately ± 50 nt about the fitted line.

Expressed in common U.S. engineering units equation (16) becomes:

$$Hp = 0.225\, W^{0.479} \qquad (17)$$

where:

Hp = the dynamometer power absorber setting at 50 mph (horsepower)

W = the vehicle weight (lb)

In this system of units the scatter of the data about the regression line is approximately ± 1.5 hp.

TWIN ROLL DYNAMOMETER FORCE ADJUSTMENT AT 50 mph

VERSUS

VEHICLE TARE

16

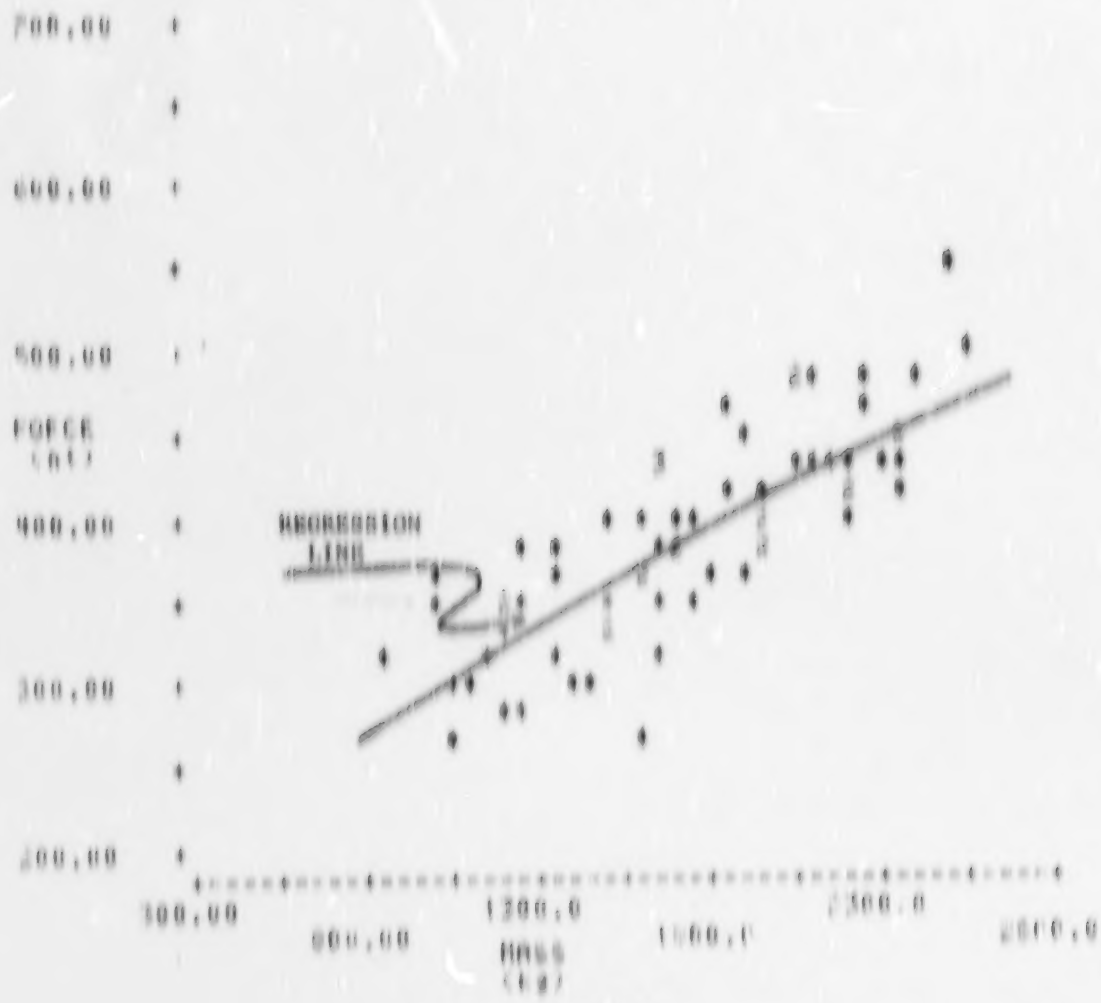


FIGURE 4

Equation (16) is probably appropriate only for vehicles fitted with tires of bias ply construction. Only one reference discusses power dissipation of radial ply tires on a small twin roll dynamometer. This reference indicates radial ply tires, inflated to 45 psi, dissipate more than twice as much power as they would on a flat surface. The data presented would indicate two radial ply tires inflated to 45 psi, dissipate as much energy on a small twin roll dynamometer as four radial ply tires inflated to 25 psi would dissipate on a flat surface. If this is a more realistic treatment of radial ply tires, then the inflation pressure corrections should not be applied to the tire rolling resistance calculations for vehicles with radial tires.

In order to test the implied difference in appropriate dynamometer power absorber settings for vehicles with radial tires, a small twin roll dynamometer adjustment setting for vehicles with radial ply tires was calculated in the same manner as the previous calculation, except the tire pressure corrections were omitted. In this case coefficients representing the total estimated rolling resistance of all four tires at normal inflation pressures, were subtracted from the total road load measurements. The resulting coefficients and the total forces and power at 50 mph are given in Table 3 of Appendix E.

A regression of the form (15) was computed to develop a prediction of the dynamometer power absorber setting versus vehicle weight. The results of this regression are:

Regression of Twin Roll Dynamometer
Force at 50 mph for Vehicles
With Radial Ply Tires

Regression Model

$\ln F = \ln a + s \ln W$

$\ln F$ = the natural logarithm of the dynamometer force (nt) setting at 50 mph

$\ln W$ = the natural logarithm of the vehicle mass (kg)

$\ln a = 2.486$

$s = 0.456$

Sample Size 68

Converting to the form of the original model:

$$F = 12.0\ W^{0.456} \qquad (18)$$

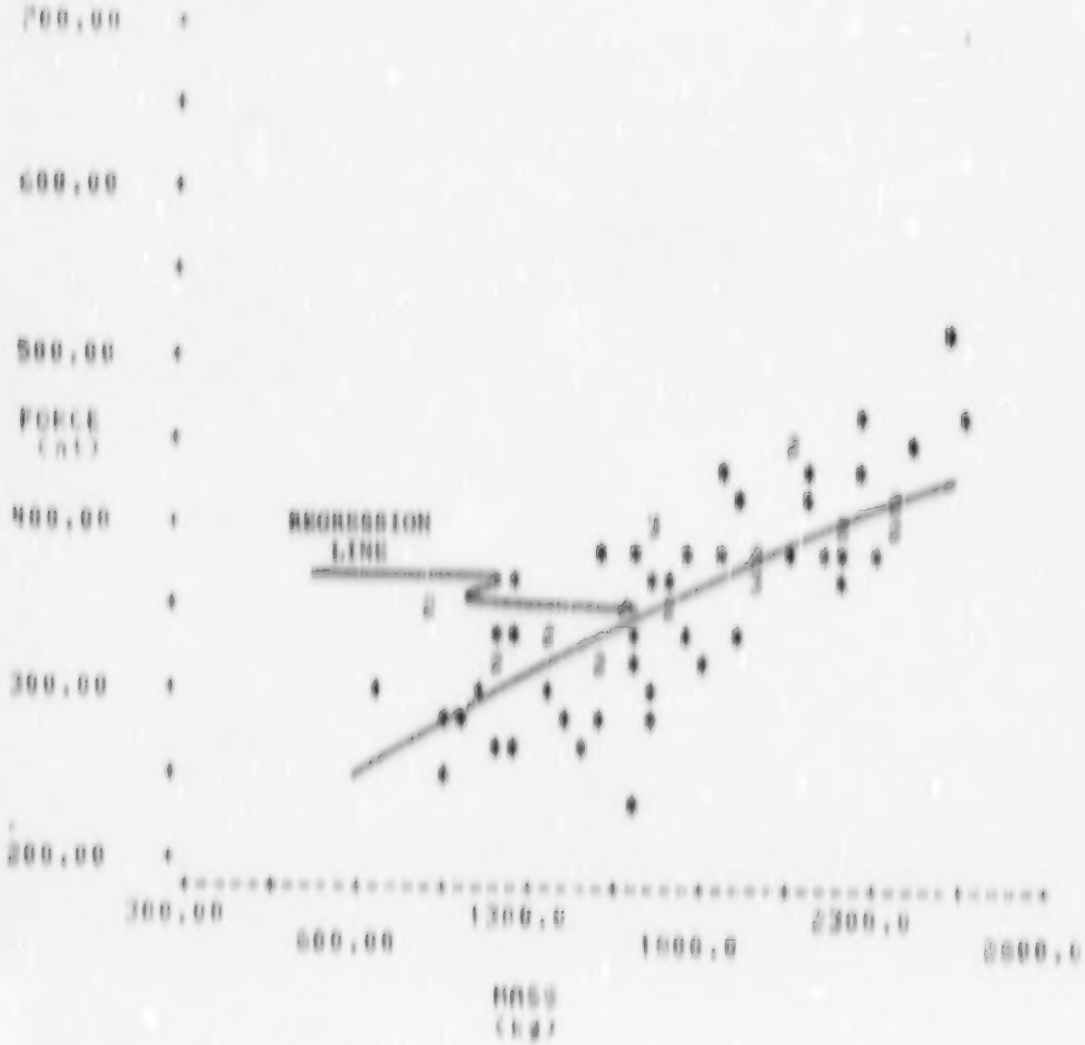
Equation (18) is plotted in Figure 5 together with the data used in the regression. Equation 18, expressed in common engineering units, is:

$$Hp = 0.251\ W^{0.456} \qquad (19)$$

ESTIMATES OF TWIN ROLL DYNAMOMETER
FORCE ADJUSTMENTS FOR VEHICLES WITH RADIAL TIRES

VERSUS

VEHICLE MASS



B. Large Roll Dynamometer Adjustment Force

Equations to predict the power absorber settings for large single roll dynamometer are developed since these equations may be useful at the present, or in future work.

The appropriate adjustment force for a large roll dynamometer can be obtained directly since the tire and drive train dissipative losses were measured on this dynamometer. To obtain the force coefficients appropriate for adjusting a 48" roll dynamometer, the coefficients of the tire and drive train losses, given in Table I of Appendix G, were subtracted from the total force coefficients, give in Table I of Appendix B. The resulting net force coefficients, representing the sum of the non driving tire and wheel bearing losses plus the vehicle aerodynamic drag, are presented in Table 4 of Appendix B. The forces at 50 mph and the appropriate power setting for a large single roll dynamometer to simulate the vehicle road load at 50 mph are also presented in Table 4.

A regression of the large roll dynamometer power absorbers setting versus vehicle mass similar to the previous regressions, was conducted.

The results were:

Regression of Large Single Roll Dynamometer
Power at 50 mph versus
Vehicle Weight

Regression model $\ln F = \ln a + s \ln M$

$\ln F$ = the natural logarithm of the dynamometer force (nt) setting at 50 mph

$\ln M$ = the natural logarithm of the vehicle mass (kg)

$\ln a$ = 1.999

s = 0.544

Sample Size 68

Converting to the form of the original model, the prediction equation is:

$$F = 7.384\ W^{0.544} \qquad (20)$$

or;

$$Hp = 0.144\ W^{0.544} \qquad (21)$$

Conclusions

The two small twin roll regression lines, equations (17) and (19) are plotted for comparison in Figure 6. Also plotted in Figure 6 are the horsepower versus weight points of the current LDV road load table. It is apparent the first regression line agrees very well with the current table, while the second equation is approximately one horsepower lower.

Dynamometer Power Absorber Setting at 50 mph

vs.

Vehicle Weight

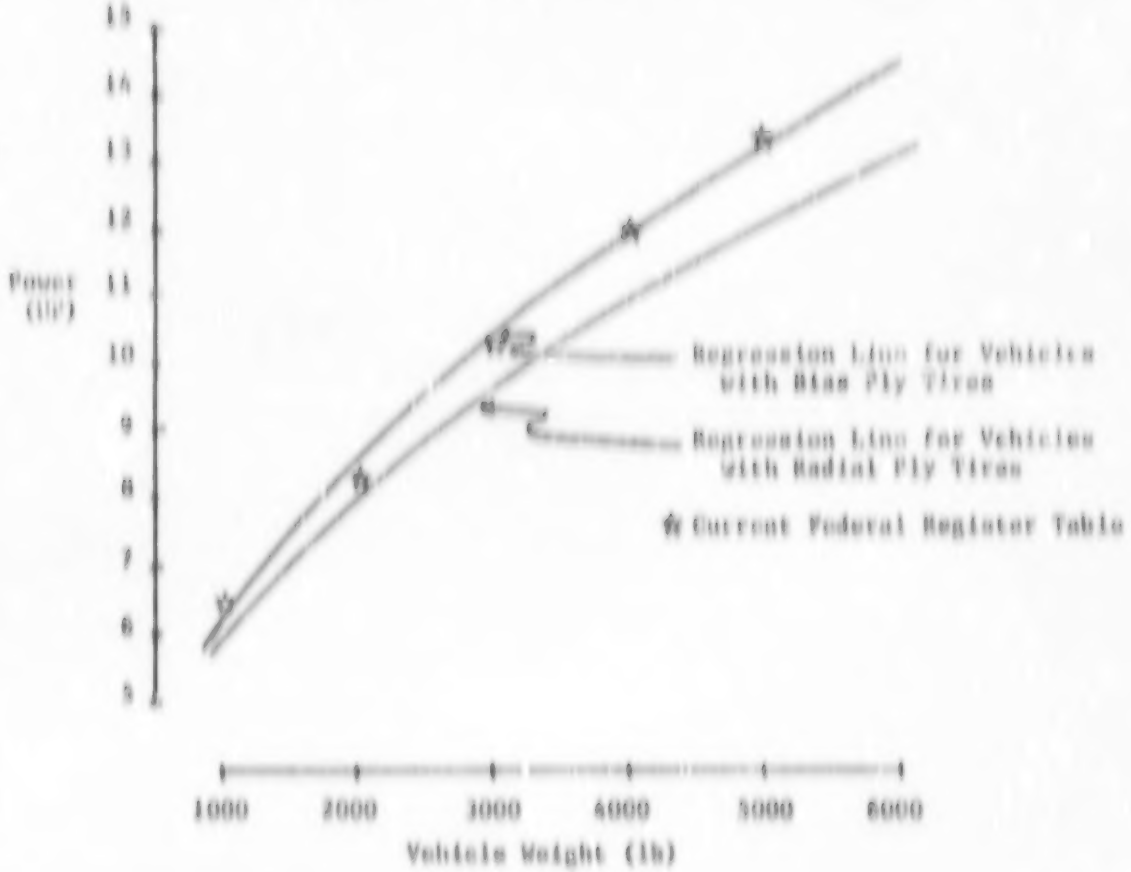


Figure 6

This indicates the current table is approximately correct for bias ply tires, but predicts higher than actual road load for vehicles with radial ply tires. The accuracy of second line is however, questionable since the tire-roll interaction assumptions used in computing this line have only been reported once in the literature. In addition, this reference only discusses measurements on a single radial ply tire. At the present time this line should be considered as an indication of the magnitude of possible radial tire effects. A limited test program to investigate tire effects in greater detail is currently in progress by the SAE Committee on Tire Rolling Resistance. A more extensive program is also currently in progress by the EPA.

The amount of data scatter observed will not be reduced by any additional tire information. It is therefore concluded that any road load prediction system based on vehicle weight will have an accuracy of approximately ± 1.5 horsepower. Two of the vehicles in the fleet, a Pontiac Lemans and a Ford Granada, were repeat tested. The variations in estimated twin roll dynamometer power absorber settings between the repeat tests were about 0.5 hp, or 4% of value in each instance. It can therefore be concluded that much of the ± 1.5 horsepower data scatter about the prediction line occurs because of the inadequacy of the regression model and is not simply random measurement error. Equation (9) followed by the corrections for tire rolling resistances demonstrate the aerodynamic forces predominate in the small twin roll dynamometer adjustment. Since there is little if any direct relationship between the vehicle weight and the aerodynamic forces on the vehicle, the vehicle weight is not a physically logical parameter to use to predict the dynamometer absorber power setting.

It is concluded that a system to predict the dynamometer power absorber setting based on the aerodynamic parameters of the vehicle should be investigated. Such a prediction system would be physically logical, and may be able to reduce the average error in predicting the dynamometer power absorber setting. Because of the theoretical advantages, a dynamometer power absorber setting prediction system based on vehicle aerodynamic parameters should be adopted. This is recommended even if it can only be shown that this would not result in a decrease in the accuracy of the prediction of the dynamometer power absorber setting compared with prediction systems based on vehicle weight.

Recommendations

It is recommended that the data from the tire studies currently in progress be incorporated into this analysis as soon as these data become available. Specifically, more information is necessary on the tire-roll interaction on small twin roll dynamometers. This information may indicate a correction factor based on the vehicle tire type should be introduced in road load prediction system.

It is also recommended that dynamometer adjustment prediction systems based on vehicle aerodynamic parameters be considered. This is the logical approach to improve the accuracy of the prediction of the dynamometer power absorber setting. This approach can also provide the incentive for improvements in the aerodynamic characteristics of vehicles.

No change in the current light duty vehicle road load table is recommended until one or both of the above improvements can be incorporated.

References

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4. G. B. Thompson, EPA Report, unpublished.

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8. S. K. Clark, "Rolling Resistance Forces in Pneumatic Tires," University of Michigan Report DOT-TSC-76-1, prepared for Department of Transportation, Transportation Systems Center, Cambridge, Mass., January 1976.

9. S. Clark, unpublished report to the SAE Subcommittee on Tire Rolling Resistance.

10. D. J. Schuring, "Rolling Resistance of Tires Measured Under Transient and Equilibrium Conditions on Calspan's Tire Research Facility," DOT-TSC-OST 76-9, March 1976.

11. C.W. LaPoint, Suggestion during telephone conversation.

APPENDIX A

VEHICLE IDENTIFICATION

Table 1

Test Fleet

Vehicle Identification Number	Model Year	Manufacturer	Model Name	Body Style	Test Weight (lbs)
101	1974	Chevrolet	Impala	Sedan	4560
201	1975	Chevrolet	Chevelle	Sedan	4100
301	1975	Pontiac	Firebird	Sedan	3640
401	1975	Pontiac	Ventura	Sedan	3520
502	1975	Ford	Pinto	Sedan	2800
601	1975	Oldsmobile	Cutlass	Sedan	4250
804	1974	American Motors	Gremlin	Sedan	2970
901	1975	Chevrolet	Impala	Stationwagon	5250
1001	1975	Chevrolet	Vega	Sedan	2600
1102	1975	Ford	Granada	Sedan	3510
1201	1975	Buick	Century	Sedan	4140
1301	1975	Buick	Special	Sedan	4070
1401	1975	Buick	Skylark	Sedan	3720
1501	1975	Buick	Apollo	Sedan	3910
1601	1975	Chevrolet	Monza	Sedan	3490
1702	1975	Ford	Mustang	Sedan	3000
1802	1975	Ford	Mustang	Sedan	3020
1904	1975	Buick	Skyhawk	Sedan	3200
2102	1975	Mercury	Capri	Sedan	2570
2203	1975	Plymouth	Valiant	Sedan	3600
2301	1975	Buick	LeSabre	Sedan	4879
2401	1975	Buick	Estate	Stationwagon	5590
2502	1975	Lincoln	Continental	Sedan	5650
2602	1974	Mercury	Capri	Sedan	2350
2706	1975	Toyota	Corolla	Sedan	2470
2802	1975	Mercury	Comet	Sedan	3320
2906	1975	Toyota	Celica	Sedan	2760
3011	1975	Saab	99	Sedan	2710
3102	1975	Ford	Mustang	Sedan	3320
3212	1975	Triumph	TR6	Convertible	2650
3304	1975	American Motors	Pacer	Sedan	3330
3401	1975	Ford	Maverick	Sedan	3350
3505	1975	Volkswagon	Rabbit	Sedan	2170
3614	1975	Honda	CVCC	Sedan	1900
3712	1975	Triumph	TR6 (1)	Convertible	2630
3808	1975	Mazda	RX-3	Stationwagon	2650
4014	1975	Fiat	128	Sedan	2160
4102	1975	Mercury	Montego	Sedan	4560
4202	1975	Ford	Gran Torino	Sedan	4570
4302	1975	Mercury	Marquis	Sedan	4900
4402	1975	Ford	LTD	Sedan	4860
4507	1975	Datsun	280Z	Sedan	3110

(1) Same vehicle as 3212, however convertible top down.

Table I con't.

Vehicle Identification Number	Model Year	Manufacturer	Model Name	Body Style	Test Weight (lbs)
4607	1975	Datsun	B210	Sedan	2310
4701	1975	Pontiac	Lemans	Sedan	4230
4801	1975	Oldsmobile	Cutlass	Sedan	4330
4903	1975	Dodge	Dart	Sedan	3610
5001	1975	Pontiac	Lemans	Sedan	4260
5103	1975	Plymouth	Valiant	Sedan	3580
5203	1975	Plymouth	Gran Fury	Sedan	4850
5303	1975	Plymouth	Scamp	Sedan	3680
5403	1975	Plymouth	Valiant	Sedan	3620
5503	1975	Chrysler	New Yorker	Sedan	5120
5603	1975	Chrysler	Newport	Sedan	4850
5601	1975	Pontiac	Lemans (2)	Sedan	4320
5701	1975	Oldsmobile	Delta 88	Sedan	4770
5802	1975	Ford	Granada	Sedan	3760
6002	1975	Mercury	Montego	Sedan	4500
6102	1975	Ford	LTD	Sedan	5020
6202	1975	Ford	Torino	Sedan	4420
6302	1975	Ford	Granada (3)	Sedan	3800
6402	1975	Ford	LTD	Sedan	5060
6502	1975	Ford	Gran Torino	Stationwagon	5210
6702	1975	Ford	Gran Torino	Stationwagon	5000
6802	1975	Ford	Torino	Sedan	4600
6909	1976	Volvo	264DL	Sedan	3190
8101	1975	Chevrolet	Corvette	Sedan	3850
8401	1975	Oldsmobile	Toronado	Sedan	5170
9101	1975	Chevrolet	Corvette (4)	Sedan	3820

(2) Same vehicle as 5001.

(3) Same vehicle as 5802.

(4) Same vehicle as 8101, however head lamps up.

APPENDIX B

TRACK MEASUREMENTS

TABLE 1
AMBIENT CORRECTED ACCELERATION COEFFICIENTS

ID	A0 (IN/SEC**2)	A1 (1/SEC)	A2 (1/IN)
101	0.11306E+00	0.19334E-02	0.27566E-03
201	0.16786E+00	-0.39356E-02	0.51925E-03
301	0.[illegible]E-01	0.[illegible]E-02	0.11[illegible]E-03
401	0.16[illegible]E+00	-0.17[illegible]E-02	0.[illegible]E-03
502	0.15[illegible]E+00	-0.2[illegible]E-02	0.[illegible]E-03
601	0.16[illegible]E+00	-0.[illegible]E-02	0.[illegible]E-03
806	0.79[illegible]E-01	0.12[illegible]E-01	0.[illegible]E-05
901	0.[illegible]E-01	0.[illegible]E-02	0.[illegible]E-03
1001	0.15[illegible]E+00	0.[illegible]E-02	0.[illegible]E-03
1102	0.[illegible]E-01	0.[illegible]E-02	0.[illegible]E-03
1201	0.[illegible]E-01	0.[illegible]E-02	0.[illegible]E-03
1301	0.[illegible]E-01	0.[illegible]E-02	0.[illegible]E-03
1401	0.[illegible]E-01	0.[illegible]E-02	0.[illegible]E-03
1501	0.[illegible]E+00	0.[illegible]E-02	0.[illegible]E-03
1601	0.12[illegible]E+00	-0.[illegible]E-03	0.[illegible]E-03
1702	0.[illegible]E-01	0.[illegible]E-02	0.[illegible]E-03
1802	0.12[illegible]E+00	0.[illegible]E-02	0.[illegible]E-03
1901	0.13[illegible]E+00	-0.[illegible]E-02	0.[illegible]E-03
2102	0.12[illegible]E+00	0.[illegible]E-02	0.[illegible]E-03
2203	0.13[illegible]E+00	-0.[illegible]E-02	0.[illegible]E-03
2301	0.[illegible]E-01	0.[illegible]E-02	0.[illegible]E-03
2401	[illegible]E-01	0.[illegible]E-02	0.[illegible]E-03
2502	[illegible]E+00	0.[illegible]E-02	0.[illegible]E-03
2602	0.11[illegible]E+00	0.[illegible]E-02	0.[illegible]E-03
2706	0.[illegible]E-01	0.[illegible]E-02	0.[illegible]E-03
2802	0.11[illegible]E+00	0.[illegible]E-02	0.[illegible]E-03
2905	0.13[illegible]E+00	-0.[illegible]E-02	0.[illegible]E-03
3011	0.[illegible]E+00	-0.[illegible]E-02	0.[illegible]E-03
3102	0.10[illegible]E+00	0.[illegible]E-02	0.[illegible]E-03
3212	0.19[illegible]E+00	-0.[illegible]E-02	0.[illegible]E-03
3306	0.11[illegible]E+00	0.[illegible]E-02	0.[illegible]E-03
3402	0.[illegible]E-01	0.[illegible]E-02	0.[illegible]E-03
3505	0.19[illegible]E+00	-0.[illegible]E-03	0.[illegible]E-03
3613	0.73[illegible]E-01	0.[illegible]E-01	0.[illegible]E-03
3712	0.12[illegible]E+00	0.[illegible]E-02	0.[illegible]E-03

B-2

TABLE 1 (CONTINUED)
AMBIENT CORRECTED ACCELERATION COEFFICIENTS

ID	A0 (M/SEC**2)	A1 (1/SEC)	A2 (1/M)
3908	0.1675E+00	0.4271E-03	0.6805E-03
4016	0.1529E+00	-0.2635E-02	0.7311E-03
4102	0.1153E+00	0.3280E-02	0.2288E-03
4202	0.7720E-01	0.2953E-02	0.8164E-04
4302	0.2610E+00	-0.1008E-01	0.7111E-03
4402	0.1176E+00	0.2971E-03	0.2944E-03
4502	0.8369E-01	0.6287E-02	0.1726E-03
4607	0.1181E+00	0.3684E-02	0.1104E-03
4701	0.1096E+00	0.1115E-03	0.3046E-03
4801	0.1041E+00	-0.2732E-03	0.3547E-03
4903	0.8101E-01	0.8044E-02	0.1011E-03
5001	0.1516E+00	-0.7771E-02	0.5147E-03
5103	0.9201E-01	0.8928E-02	0.1458E-03
5203	0.1063E+00	0.3068E-02	0.2194E-03
5303	0.1013E+00	0.7489E-02	0.1581E-03
5403	0.1679E+00	-0.8035E-02	0.4844E-03
5503	0.1606E+00	-0.1624E-02	0.3902E-03
5601	0.9701E-01	0.3522E-02	0.2115E-03
5703	0.8000E-01	0.7376E-02	0.1024E-03
5701	0.1022E+00	0.3863E-02	0.2134E-03
5802	0.9902E-01	0.4481E-02	0.2453E-03
6002	0.1193E+00	0.4866E-02	0.1808E-03
6102	0.8200E-01	0.7494E-02	0.8059E-04
6202	0.7894E-01	0.8866E-02	0.1223E-03
6302	0.1270E+00	-0.7405E-02	0.4087E-03
6402	0.8240E-01	0.6094E-02	0.1516E-03
6502	0.8869E-01	0.3702E-02	0.2284E-03
6702	0.8996E-01	0.2250E-02	0.3168E-03
6802	0.1311E+00	-0.3504E-02	0.4599E-03
6904	0.8843E-01	0.7823E-02	0.2174E-03
8101	0.1516E+00	-0.5870E-02	0.4934E-03
8401	0.1030E+00	0.2531E-02	0.2266E-03
9101	0.1294E+00	0.2704E-02	0.2673E-03

TABLE B

TRACK AMBIENT CONDITIONS

VEHICLE ID	TEST DATE	DRY BULB TEMP (F)	WET BULB TEMP (F)	BAROMETRIC STATION PRESSURE (IN HG)	MEAN WIND SPEED (MPH)
101	7 15 75	70.0	63.0	29.00	5.1
201	7 15 75	75.0	66.0	28.98	6.8
301	7 17 75	72.0	65.0	29.00	0.0
401	7 17 75	77.0	69.0	29.00	5.3
501	7 17 75	81.0	70.0	28.98	7.1
502	7 17 75	85.0	71.0	28.80	5.9
601	7 22 75	92.0	71.5	28.84	3.8
806	7 22 75	88.0	69.5	28.84	6.0
901	7 22 75	76.0	71.0	28.88	4.2
1001	7 24 75	72.0	67.0	28.78	6.8
1102	7 25 75	74.0	66.0	28.80	3.4
1201	7 25 75	75.5	66.5	28.79	6.8
1301	7 25 75	74.5	66.0	28.80	6.2
1401	7 25 75	86.0	66.5	28.81	7.3
1501	7 25 75	86.0	65.0	28.80	5.9
1601	7 25 75	73.0	65.0	28.83	2.6
1702	7 29 75	80.0	68.0	28.84	3.6
1802	7 29 75	84.0	68.0	28.96	6.6
1901	7 29 75	86.5	69.0	28.94	3.7
2102	7 30 75	91.0	69.0	28.94	5.9
2203	7 30 75	92.0	68.5	28.96	3.8
2301	7 30 75	95.0	70.0	28.91	2.8
2401	7 30 75	74.0	69.0	28.95	0.6
2502	7 31 75	82.0	70.0	28.96	0.0
2602	8 1 75	85.0	70.0	28.96	0.1
2706	8 1 75	90.0	70.0	28.94	2.1
2802	8 1 75	91.0	70.0	28.90	3.7
2906	8 1 75	76.0	69.5	28.74	1.6
3011	8 5 75	77.0	70.0	28.74	0.1
3102	8 5 75	81.5	71.0	28.74	3.3
3212	8 5 75	87.0	70.0	28.70	2.5
3304	8 5 75	65.7	59.0	28.91	5.8
3402	8 7 75	67.5	60.0	28.91	7.0
3505	8 7 75	68.5	60.0	28.92	8.3
3613	8 7 75	76.0	61.0	28.90	6.5
3712	8 7 75	87.5	71.5	28.85	7.9
3908	8 26 75	70.0	64.5	29.06	2.3
4014	8 27 75	75.5	65.0	29.10	1.5
4102	8 27 75	78.0	66.0	29.10	2.7
4202	8 27 75				

TABLE 2 (CONTINUED)

TRACK AMBIENT CONDITIONS

VEHICLE ID	TEST DATE	DRY BULB TEMP (F)	WET BULB TEMP (F)	BAROMETRIC STATION PRESSURE (IN HG)	MEAN WIND SPEED (MPH)
4302	8 27 75	81.0	66.5	29.08	3.1
4602	8 27 75	80.8	65.0	29.06	3.5
4507	8 27 75	85.5	68.0	29.05	2.6
4807	8 27 75	87.5	65.0	29.02	1.8
4701	8 27 75	88.0	65.5	29.00	2.1
4801	8 27 75	84.0	65.5	29.02	1.0
4903	8 28 75	78.8	64.0	29.02	1.7
5001	8 28 75	73.5	65.0	29.02	5.6
5102	8 28 75	74.0	65.5	29.02	4.9
5203	8 28 75	82.0	67.0	29.00	6.0
5303	8 28 75	87.0	67.5	28.98	6.8
5403	8 28 75	89.5	68.0	28.96	6.8
5503	8 28 75	89.0	67.5	28.96	7.9
5603	8 28 75	87.5	68.0	28.97	5.4
4801	8 29 75	78.5	69.0	29.00	4.0
5701	8 29 75	77.0	71.0	29.04	8.5
5802	8 29 75	77.5	71.0	29.02	9.3
6002	9 9 75	80.0	66.0	29.10	6.2
6102	9 9 75	87.0	81.0	29.10	6.4
6202	9 9 75	71.0	63.0	29.10	6.6
6302	9 9 75	73.0	67.0	29.10	3.0
6402	9 10 75	80.5	66.0	29.00	5.3
6502	9 10 75	75.0	69.0	28.99	7.0
6702	9 10 75	73.0	68.0	28.98	6.0
6802	9 10 75	70.0	66.0	28.98	5.8
6904	9 22 75	68.5	62.5	28.92	4.4
8101	10 03 75	75.0	69.0	28.99	6.7
8401	10 06 75	71.0	67.0	28.92	5.7
9101	10 16 75	82.0	66.0	28.98	3.0

TABLE 3

TRACK TIRE PRESSURES

VEHICLE ID	INITIAL PRESSURES		FINAL PRESSURES			
	FRONT (PSI)	REAR (PSI)	FRONT (PSI)		REAR (PSI)	
101	28.0	28.0	30.5	30.0	30.5	30.5
201	24.0	24.0	27.5	27.5	27.0	27.5
301	26.0	26.0	29.1	24.3	27.1	27.0
401	24.0	24.0	28.0	27.5	27.5	27.5
502	24.0	24.0	27.2	27.1	25.5	27.0
601	26.0	26.0	24.7	24.5	30.0	30.0
806	24.0	24.0	28.1	28.7	27.4	27.5
901	32.0	32.0	25.7	25.4	36.4	36.2
1001	24.0	24.0	28.0	28.0	28.0	28.0
1102	24.0	24.0	27.4	27.7	29.4	29.0
1201	26.0	26.0	24.5	24.2	30.0	24.7
1301	32.0	32.0	35.0	35.2	35.2	35.0
1401	24.0	24.0	27.5	27.4	27.7	27.4
1501	28.0	32.0	30.5	30.5	29.4	29.8
1601	30.0	32.0	33.0	33.2	35.4	33.0
1702	26.0	26.0	29.4	29.2	30.1	29.2
1802	26.0	26.0	24.8	24.5	30.0	30.0
1901	24.0	26.0	27.7	27.7	29.5	29.5
2102	27.0	31.0	27.3	27.0	34.4	34.1
2203	28.0	28.0	32.5	32.5	33.0	32.5
2301	26.0	26.0	29.5	29.5	31.7	31.0
2401	24.0	28.0	27.5	27.5	32.0	32.0
2502	26.0	26.0	29.7	29.5	30.0	30.0
2602	27.0	31.0	29.0	32.7	29.0	33.0
2703	26.0	26.0	26.0	26.0	26.5	26.0
2802	26.0	26.0	27.0	26.5	29.0	29.0
2906	26.0	26.0	27.0	26.5	26.0	27.5
3011	27.0	27.0	26.5	29.0	29.0	28.7
3102	26.0	26.0	26.5	28.0	28.0	29.0
3212	26.0	26.0	22.2	22.5	26.2	25.5
3306	26.0	26.0	26.3	26.2	26.0	27.5
3402	26.0	26.0	27.0	27.5	29.5	29.0
3505	27.0	27.0	29.2	28.5	28.5	28.5
3613	22.7	22.7	26.0	26.0	26.2	25.2
3712	26.0	26.0	21.2	22.0	26.0	26.2
3808	26.0	26.0	29.5	29.5	29.5	31.0
4016	26.0	26.0	28.5	28.5	26.5	26.5
4102	26.0	26.0	28.2	28.0	28.5	29.0
4202	26.0	26.0	29.5	28.2	29.5	28.8

TABLE 3 (CONTINUED)

TRACK TIRE PRESSURES

VEHICLE ID	INITIAL PRESSURES FRONT (PSI)	INITIAL PRESSURES REAR (PSI)	FINAL PRESSURES FRONT (PSI)		FINAL PRESSURES REAR (PSI)	
4302	26.0	26.0	29.4	29.5	30.2	29.8
4402	26.0	26.0	30.0	29.2	29.5	29.5
4507	28.0	28.0	31.0	30.2	33.2	31.2
4607	24.0	24.0	28.0	27.0	27.8	26.5
4701	28.0	30.0	31.0	30.5	34.0	32.5
4801	28.0	28.0	30.8	30.5	30.8	30.5
4903	28.0	28.0	32.0	31.5	33.0	32.5
5001	28.0	30.0	32.0	33.5	33.5	32.0
5103	28.0	28.0	31.5	31.5	31.5	31.2
5203	26.0	26.0	29.5	30.0	33.5	29.2
5303	28.0	28.0	32.0	32.0	32.5	31.8
5403	28.0	28.0	32.0	32.0	32.0	31.5
5503	26.0	26.0	28.0	27.5	28.0	27.8
5603	26.0	26.0	29.0	28.5	29.5	29.0
5601	28.0	30.0	32.0	33.5	33.5	32.0
5701	26.0	28.0	29.5	29.8	31.5	31.5
5802	26.0	26.0	27.0	27.0	26.5	26.5
6002	26.0	26.0	27.0	26.0	27.2	27.0
6102	26.0	26.0	30.2	30.5	31.0	31.0
6202	26.0	26.0	27.8	27.0	28.5	29.0
6302	26.0	26.0	27.4	26.0	27.5	26.2
6602	26.0	26.0	29.5	29.8	30.0	29.8
6502	28.0	32.0	27.5	27.5	30.5	30.5
6702	26.0	32.0	27.0	27.0	30.5	30.0
6802	26.0	26.0	28.8	28.0	27.5	29.0
6902	25.0	26.0	26.5	27.0	28.2	29.0
8101	20.0	20.0	23.3	23.3	23.5	23.5
8401	20.0	20.0	30.5	30.5	25.8	25.0
9101	20.0	20.0	22.0	21.5	22.5	22.0

APPENDIX C

DYNAMIC TEST MEASUREMENTS

B-1

TABLE I
DRIVE TRAIN + DRIVING TIRE

REGRESSION COEFFICIENTS

ID	A (NT)	B (NT/SEC)
101	101.717	2.349
201	72.340	2.596
301	82.378	2.395
401	102.174	1.802
502	66.274	1.755
601	48.210	2.171
804	91.133	2.114
401	120.495	2.504
1001	80.000	2.143
1102	67.356	4.091
1201	95.005	3.026
1301	61.112	3.009
1401	73.966	2.524
1501	113.277	1.802
1601	67.916	2.077
1702	78.165	1.898
1802	101.203	1.175
1901	61.621	1.567
2102	60.434	2.102
2203	66.758	1.400
2301	127.401	1.518
2401	105.734	3.097
2502	93.789	1.852
2602	62.382	1.777
2705	50.067	1.482
2802	42.190	3.390
2906	57.292	1.056
3011	46.490	0.470
3102	93.368	1.118
3212	90.314	1.221
3304	101.032	2.452
3402	86.279	1.617
3502	24.601	0.631
3614	58.198	1.647
3712	90.314	1.221
3806	88.477	1.607
4014	32.606	0.923
4102	140.387	0.813
4202	127.091	1.956
4302	77.169	2.191
4402	102.101	2.117

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TABLE 1 (CONTINUED)

DRIVE TRAIN + DRIVING TIME

REGRESSION COEFFICIENTS

ID	A (INT)	B (INCH/SEC)
4607	97.320	1.666
4607	63.221	1.961
4701	90.043	1.971
4801	107.353	1.803
4901	92.254	2.271
5001	94.980	3.248
5101	79.335	2.799
5201	81.965	3.295
5301	59.476	3.111
5401	80.695	2.372
5501	37.298	4.403
5601	59.980	3.258
5603	103.096	2.572
5701	115.754	1.660
5802	83.098	1.634
6002	121.569	1.259
6102	113.579	1.302
6202	66.157	4.361
6302	81.096	1.639
6402	134.917	1.155
6502	136.316	1.956
6702	103.470	2.808
6802	68.876	3.516
6902	68.550	1.798
8101	107.667	1.665
8401	198.491	0.215
9101	107.667	1.685

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TABLE 4
DRIVING TIME

REGRESSION COEFFICIENTS

ID	A (INT)	B (MG/SEC)
101	76.182	0.635
201	69.652	0.819
301	76.373	0.305
401	71.451	0.284
502	55.387	0.143
601	68.166	0.617
604	79.993	0.730
001	74.351	1.049
001	76.784	0.276
1102	80.407	0.708
1201	98.172	-0.789
1301	66.631	0.676
1401	50.241	1.000
1501	86.593	-0.608
1601	31.212	0.637
1702	50.213	0.564
1802	73.260	0.297
1901	53.471	0.656
2102	66.883	0.500
2203	66.169	-0.631
2301	89.550	0.364
2401	80.606	0.995
2502	61.021	0.639
2602	37.919	0.138
2705	-0.761	1.000
2802	27.733	0.510
2906	67.383	0.630
3011	31.906	0.324
3102	64.702	0.139
3212	49.004	0.119
3304	79.946	0.798
3402	66.990	0.607
3505	18.437	0.167
3613	67.617	0.175
3712	69.000	0.119
3908	66.001	0.066
4018	26.975	0.324
4102	132.246	0.504
4202	85.202	0.868
4302	61.592	0.699
4402	64.730	0.586

TABLE 2 (CONTINUED)

DRIVING TIME

REGRESSION COEFFICIENTS

ID	A (MIN)	B (MIN/SEC)
4501	62.980	0.264
4607	47.277	0.437
4701	67.355	0.672
4801	69.927	0.541
4903	66.060	0.570
5001	60.255	0.815
5103	58.705	0.575
5203	47.075	0.160
5303	40.020	1.540
5403	79.322	0.533
5503	55.476	0.760
5601	60.255	0.815
5653	66.405	0.658
5701	76.031	0.858
5802	64.147	0.342
6002	70.702	0.412
6102	87.241	0.589
6202	75.627	0.692
6302	64.147	0.342
6402	97.064	0.420
6502	64.242	0.503
6702	33.696	0.119
6802	53.527	0.768
6904	47.097	-0.018
8101	59.739	0.407
8401	70.415	-0.035
9101	59.739	0.407

TABLE 1
DRIVE TRAIN

REGRESSION COEFFICIENTS

ID	A (NT)	B (RAD/SEC)
101	25.335	1.710
201	2.079	1.786
301	6.004	2.000
401	34.923	1.913
502	19.850	1.810
601	30.080	1.595
805	11.160	1.486
903	66.553	1.459
1001	3.310	1.867
1102	46.454	1.383
1201	-3.360	1.115
1301	21.000	2.520
1401	19.729	1.592
1501	32.063	2.241
1601	28.706	1.040
1702	21.462	1.330
1802	27.960	0.870
1901	8.160	0.711
2102	14.356	1.521
2203	22.564	2.033
2301	38.432	1.153
2401	17.110	2.102
2502	2.724	1.212
2602	25.463	1.960
2706	56.810	-0.053
2802	14.658	2.471
2900	10.004	1.450
3011	15.054	0.692
3102	23.067	0.479
3212	41.318	1.102
3304	21.476	1.655
3402	21.203	0.930
3503	9.364	0.955
3613	6.778	1.523
3712	41.315	1.102
3908	42.479	1.584
4014	5.712	0.524
4102	8.163	0.308
4202	42.689	0.586
4302	19.708	1.820
4402	33.172	1.011

TABLE 4 (CONTINUED)

DRIVE TRAIN

REGRESSION COEFFICIENTS

ID	A (NT)	B (KG/SEC)
4507	34.164	1.193
4607	15.484	1.106
4701	22.083	1.234
4801	37.420	1.201
4903	16.316	1.709
5001	-0.275	2.432
5103	16.579	2.228
5203	34.470	1.093
5303	14.053	1.570
5403	1.174	1.834
5503	-14.191	0.636
5601	-0.275	2.432
5703	36.690	1.213
5701	34.723	0.002
5802	18.960	1.293
6002	30.888	0.761
6102	25.230	1.220
6202	18.930	1.268
6302	18.948	1.293
6402	37.347	1.124
6502	67.073	1.373
6702	14.773	2.764
6802	15.168	2.764
6902	21.453	1.813
8101	47.929	0.778
8401	127.366	0.250
9101	47.929	0.778

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TABLE 4
NON-DRIVING TIME

REGRESSION COEFFICIENTS

ID	A (MIL)	B (MSEC/SEC)
101	119.778	0.597
201	124.040	0.528
301	123.040	0.525
401	119.314	0.616
501	81.905	0.052
601	72.462	0.100
801	100.238	0.536
901	104.881	-0.011
1001	92.513	0.216
1101	50.424	0.423
1201	91.932	0.326
1301	93.028	0.234
1401	46.115	0.407
1501	123.040	0.525
1601	86.202	0.715
1702	69.056	0.560
1802	74.500	0.616
1901	82.243	0.584
2102	67.595	0.601
2203	21.178	1.494
2301	100.010	0.097
2401	86.180	1.013
2502	75.572	-0.124
2602	16.797	0.008
2706	97.007	0.590
2802	100.700	0.307
2906	35.764	0.520
3011	16.202	0.236
3102	92.567	0.377
3212	96.007	0.271
3304	100.230	0.536
3402	104.100	0.305
3505	16.797	0.008
3613	20.527	0.004
3712	96.007	0.271
3908	93.398	0.600
4014	39.645	0.062
4102	95.874	-0.020
4202	135.000	0.615
4302	124.002	0.230
4402	145.133	0.059

TABLE 4 (CONTINUED)

NON-DRIVING TIME

REGRESSION COEFFICIENTS

ID	A (MPH)	B (MPH/MPH)
4501	58.140	-0.063
4601	62.750	0.134
4701	62.457	0.142
4801	86.218	0.383
4901	109.716	0.603
5001	80.000	0.415
5101	92.503	0.313
5201	122.507	-0.273
5301	92.874	0.402
5401	92.502	0.666
5501	119.054	0.305
5601	80.000	0.415
5603	103.000	0.803
5701	129.501	0.000
5802	101.203	0.247
6002	103.810	-0.190
6102	117.000	0.305
6202	153.539	0.196
6302	101.203	0.597
6402	126.000	0.000
6502	126.724	0.276
6702	77.571	0.170
6802	86.098	0.308
6902	62.048	0.306
8101	79.234	0.361
8502	81.011	0.360
9101	79.239	0.361

TABLE 5

DYNAMOMETER TEST CONDITIONS

VEHICLE ID	TEMP (F)	INITIAL TIRE PRESSURES FRONT (PSI)	INITIAL TIRE PRESSURES REAR (PSI)	FINAL TIRE PRESSURES FRONT (PSI)		FINAL TIRE PRESSURES REAR (PSI)	
101	73.0	28.0	28.0	32.3	31.9	31.5	31.9
201			24.0			25.5	25.5
301			24.0			26.0	26.0
401	75.0	26.0	24.0	28.7	27.9	27.0	27.0
502	73.0	22.0	22.0			26.0	26.0
601	74.0	26.0	26.0	31.1	30.5	28.5	28.0
806		24.0	24.0			27.0	28.4
901	76.0	22.0	32.0	25.7	25.7	35.5	36.0
1001	76.0					29.0	28.0
1102	73.0	26.0	26.0	29.0	28.0	26.5	26.0
1201	76.0	26.0	26.0	27.0	26.7	27.2	27.0
1301	78.0	32.0	32.0	36.0	35.6	35.0	35.0
1401	75.0	24.0	24.0	28.1	28.0	27.6	28.0
1501	76.0	26.0	26.0	30.6	30.3	28.0	28.0
1601	74.0	30.0	32.0	34.9	34.2	35.8	36.0
1702	74.0	26.0	26.0	29.0	29.5	29.5	29.5
1802	74.0	26.0	26.0	28.8	29.7	28.4	28.6
1901	78.0	24.0	26.0	27.2	28.2	28.5	28.5
2102	75.0	27.0	31.0	29.9	30.1	35.2	35.0
2203	76.0	28.0	28.0	30.0	30.8	31.9	31.2
2301	74.0	24.0	24.0	26.5	26.5	30.0	29.5
2401	75.0	24.0	28.0	27.6	28.0	33.9	34.1
2502	73.0	26.0	26.0	29.0	29.0	29.0	30.0
2602			31.0				
2706	76.0	24.0	24.0	26.0	26.0	25.5	26.0
2802	76.0	24.0	26.0	28.0	28.0	28.8	28.8
2906	75.0	24.0	24.0	25.7	25.8	25.3	25.7
3011	73.0	27.0	27.0	30.0	30.0	30.0	30.0
3102	75.0	26.0	26.0	29.2	29.2	28.8	28.8
3212	78.0	20.0	24.0	21.2	21.7	26.0	26.0
3306	76.0	26.0	29.0	30.6	30.9		
3402	76.0	24.0	26.0	28.6	28.8	29.8	30.4
3503	76.0						
3613	75.0	22.7	22.7	28.0	28.0	22.7	22.7
3712							
3908	76.0	26.0	26.0	30.6	31.2	29.8	29.0
4015		26.0	24.0	29.0	29.2	26.0	26.0
4102	76.0	24.0	24.0	26.2	25.8	27.5	27.5
4202	72.0	24.0	24.0	29.6	29.6	29.6	29.0

TABLE 5 (CONTINUED)

DYNAMOMETER TEST CONDITIONS

VEHICLE ID	TEMP (F)	INITIAL TIRE PRESSURES		FINAL TIRE PRESSURES			
		FRONT (PSI)	REAR (PSI)	FRONT (PSI)		REAR (PSI)	
4302	74.0	26.0	26.0	29.0	29.1		
4602	75.0	26.0	26.0	32.0	31.5	30.9	30.6
4507	74.0	28.0	28.0	32.3	32.3	33.3	33.8
4607	75.0	24.0	24.0	29.2	29.0	27.8	28.2
4701	76.0	26.0	26.0	30.4	30.7	29.4	28.9
4801	76.0	24.0	24.0	29.0	29.8	29.5	29.7
4903	73.0	28.0	28.0	33.0	33.0	31.0	31.0
5001							
5101	74.0	28.0	28.0	32.0	32.6	31.8	31.2
5203	75.0	26.0	26.0	29.2	29.0	29.4	29.8
5303	75.0	28.0	28.0	34.5	34.4	33.2	33.0
5403	76.0	28.0	30.0	33.3	33.0	33.8	34.0
5503	76.0	24.0	24.0	28.1	28.9	29.0	28.0
5603	75.0	26.0	26.0	31.4	31.0	29.5	30.1
5601	75.0	24.0	24.0	30.7	31.7	28.7	28.7
5701	74.0	26.0	26.0	32.1	32.1	30.0	31.2
5802	74.0	26.0	24.0	27.4	26.8	26.6	26.0
6002	73.0	26.0	24.0	26.0	27.2		
6102	74.0	26.0	26.0	30.1	30.6	32.0	31.0
6202	75.0	24.0	24.0	29.2	29.4	28.0	28.5
6302							
6402	75.0	26.0	26.0	30.4	30.8	27.0	27.2
6502	76.0	24.0	24.0	26.8	26.8	39.7	39.0
6702	76.0	24.0	32.0	25.6	25.5	35.0	35.5
6802	74.0	26.0	24.0	28.0	27.5	28.2	28.2
6902	76.0	24.0	26.0	27.8	27.0	28.0	28.2
8101	72.0	26.0	26.0	22.2	22.2	23.5	23.0
8601	73.0	26.0	26.0	30.5	31.6	21.0	21.5
9101	72.0	26.0	26.0	22.2	22.2	23.5	23.0

APPENDIX II

PASSES

B-1

TABLE 1
VEHICLE MASSES

ID	UNIT EMPTY MASS (KG)	UNIT FULL MASS (KG)	GROSS MASS (KG)	TOTAL VEH MASS (KG)
101	23.14	32.11	207.73	215.11
201	21.10	28.91	100.56	143.50
301	20.86	25.67	150.50	170.11
401	21.22	24.82	160.00	166.05
502	17.75	19.75	127.73	131.22
601	23.50	24.97	143.18	148.77
801	17.13	20.35	115.00	130.47
901	27.34	37.82	235.35	250.73
1001	16.31	18.91	121.18	123.34
1102	22.01	24.75	154.65	164.21
1201	23.44	24.20	188.82	193.11
1301	24.91	28.32	162.67	168.11
1401	21.82	26.21	169.41	173.47
1501	17.94	21.57	177.21	182.13
1601	20.47	24.61	150.36	156.84
1702	18.50	21.16	135.10	140.36
1802	19.67	21.30	137.23	141.59
1901	16.61	22.57	149.10	154.78
2102	16.61	18.12	116.12	120.47
2201	20.50	25.34	103.36	108.26
2301	25.62	30.34	221.30	227.50
2401	27.30	34.82	250.91	258.71
2502	28.31	30.43	241.77	254.11
2602	15.67	16.57	106.12	110.62
2705	17.51	17.82	112.73	113.65
2802	21.34	23.61	150.04	155.32
2902	14.14	14.66	125.55	129.26
3011	17.51	14.11	123.11	124.44
3102	19.14	23.41	150.04	151.11
3212	20.05	18.69	120.53	124.10
3304	16.65	23.62	151.56	155.57
3402	21.22	24.82	155.41	160.42
3503	14.61	15.31	98.10	101.10
3613	11.27	13.40	86.36	88.11
3712	22.06	18.64	120.53	124.10
3808	16.73	18.90	121.18	125.13
4015	12.71	15.37	94.10	101.49
4102	24.90	32.16	207.73	213.83
4202	25.56	32.21	211.77	217.30
4302	24.03	30.14	200.14	206.31
4402	22.54	30.27	200.14	206.91

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TABLE 1 [illegible]
VEHICLE MASSES

[illegible]	[illegible] MASS (KG)	[illegible] MASS (KG)	GVWR MASS (KG)	TOTAL VEH MASS (KG)
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

APPENDIX E

VEHICLE ROAD LOAD

AND

DYNAMOMETER ADJUSTMENT TO SIMULATE VEHICLE ROAD LOAD

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TABLE I
TOTAL VEHICLE ROAD LOAD

ID	GRAVMASS (KG)	F0 (LBF)	F1 (LBF/MPH)	F2 (LBF/MPH)	P@50 (HP)	HP@50 (HP)
101	2072.7	0.2[illegible]E+03	0.[illegible]E+01	0.[illegible]E+00	0.[illegible]E+03	18.[illegible]
201	1863.6	0.[illegible]E+03	-0.[illegible]E+01	0.[illegible]E+00	0.[illegible]E+03	19.[illegible]
301	1634.6	0.[illegible]E+03	0.[illegible]E+01	0.[illegible]E+00	0.[illegible]E+03	15.[illegible]
401	1606.0	0.[illegible]E+03	-0.[illegible]E+01	0.[illegible]E+00	0.[illegible]E+03	16.[illegible]
502	1272.7	0.[illegible]E+03	-0.[illegible]E+01	0.[illegible]E+00	0.[illegible]E+03	14.[illegible]
601	1931.0	0.[illegible]E+03	-0.[illegible]E+01	0.[illegible]E+00	0.[illegible]E+03	17.[illegible]
701	1750.0	0.[illegible]E+03	0.[illegible]E+02	0.[illegible]E+00	0.[illegible]E+03	16.[illegible]
801	2300.0	0.[illegible]E+03	0.[illegible]E+01	0.[illegible]E+00	0.[illegible]E+03	20.[illegible]
1001	1218.2	0.[illegible]E+03	0.[illegible]E+01	0.[illegible]E+00	0.[illegible]E+03	15.[illegible]
1102	1395.4	0.[illegible]E+03	0.[illegible]E+01	0.[illegible]E+00	0.[illegible]E+03	17.[illegible]
1201	1881.8	0.[illegible]E+03	0.[illegible]E+02	0.[illegible]E+00	0.[illegible]E+03	17.[illegible]
1301	1827.3	0.[illegible]E+03	0.[illegible]E+02	0.[illegible]E+00	0.[illegible]E+03	17.[illegible]
1401	1540.9	0.[illegible]E+03	0.[illegible]E+02	0.[illegible]E+00	0.[illegible]E+03	16.[illegible]
1501	1777.3	0.[illegible]E+03	0.[illegible]E+01	0.[illegible]E+00	0.[illegible]E+03	17.[illegible]
1601	1536.4	0.[illegible]E+03	-0.[illegible]E+01	0.[illegible]E+00	0.[illegible]E+03	12.[illegible]
1702	1363.6	0.[illegible]E+03	0.[illegible]E+01	0.[illegible]E+00	0.[illegible]E+03	14.[illegible]
1802	1372.7	0.[illegible]E+03	0.[illegible]E+01	0.[illegible]E+00	0.[illegible]E+03	15.[illegible]
1901	1454.6	0.[illegible]E+03	-0.[illegible]E+01	0.[illegible]E+00	0.[illegible]E+03	12.[illegible]
2102	1168.2	0.[illegible]E+03	0.[illegible]E+01	0.[illegible]E+00	0.[illegible]E+03	13.[illegible]
2203	1618.4	0.[illegible]E+03	-0.[illegible]E+01	0.[illegible]E+00	0.[illegible]E+03	15.[illegible]
2301	1822.6	0.[illegible]E+03	0.[illegible]E+01	0.[illegible]E+00	0.[illegible]E+03	18.[illegible]
2401	2540.9	0.[illegible]E+03	0.[illegible]E+01	0.[illegible]E+00	0.[illegible]E+03	21.[illegible]
2502	2477.3	0.[illegible]E+03	0.[illegible]E+01	0.[illegible]E+00	0.[illegible]E+03	19.[illegible]
2602	1618.2	0.[illegible]E+03	0.[illegible]E+01	0.[illegible]E+00	0.[illegible]E+03	12.[illegible]
2703	1822.7	0.[illegible]E+02	0.[illegible]E+01	0.[illegible]E+00	0.[illegible]E+03	12.[illegible]
2802	1509.1	0.[illegible]E+03	0.[illegible]E+01	0.[illegible]E+00	0.[illegible]E+03	13.[illegible]
2906	1254.6	0.[illegible]E+03	-0.[illegible]E+01	0.[illegible]E+00	0.[illegible]E+03	11.[illegible]
3011	1231.8	0.[illegible]E+03	-0.[illegible]E+01	0.[illegible]E+00	0.[illegible]E+03	13.[illegible]
3102	1504.1	0.[illegible]E+03	0.[illegible]E+01	0.[illegible]E+00	0.[illegible]E+03	15.[illegible]
3214	1700.6	0.[illegible]E+03	-0.[illegible]E+01	0.[illegible]E+00	0.[illegible]E+03	12.[illegible]
3304	1313.6	0.[illegible]E+03	0.[illegible]E+01	0.[illegible]E+00	0.[illegible]E+03	15.[illegible]
3402	1590.9	0.[illegible]E+03	0.[illegible]E+02	0.[illegible]E+00	0.[illegible]E+03	16.[illegible]
3503	1386.4	0.[illegible]E+03	-0.[illegible]E+00	0.[illegible]E+00	0.[illegible]E+03	11.[illegible]
3611	1363.6	0.[illegible]E+02	0.[illegible]E+02	0.[illegible]E+00	0.[illegible]E+03	11.[illegible]
3712	1704.6	0.[illegible]E+03	0.[illegible]E+01	0.[illegible]E+00	0.[illegible]E+03	14.[illegible]
3808	1318.2	0.[illegible]E+03	0.[illegible]E+00	0.[illegible]E+00	0.[illegible]E+03	14.[illegible]
4014	940.9	0.[illegible]E+03	-0.[illegible]E+01	0.[illegible]E+00	0.[illegible]E+03	11.[illegible]
4102	2072.7	0.[illegible]E+03	0.[illegible]E+01	0.[illegible]E+00	0.[illegible]E+03	17.[illegible]
4202	2077.3	0.[illegible]E+03	0.[illegible]E+02	0.[illegible]E+00	0.[illegible]E+03	21.[illegible]
4302	2208.2	0.[illegible]E+03	-0.[illegible]E+02	0.[illegible]E+01	0.[illegible]E+03	17.[illegible]
4402	2207.1	0.[illegible]E+03	0.[illegible]E+00	0.[illegible]E+00	0.[illegible]E+03	18.[illegible]

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TABLE 1 (CONTINUED)
TOTAL VEHICLE ROAD LOAD

ID	GHA/MASS (KG)	F0 (N)	F1 (KG/SEC)	F2 (KG/M)	F=50 (N)	MPH=50 (MPH)
4907	1413.0	0.121[illegible]E+03	[illegible]E+01	0.[illegible]E+00	0.4522E+03	13.[illegible]
4907	1540.0	0.127[illegible]E+03	0.34[illegible]E+01	0.33[illegible]E+00	0.3033E+03	11.4907
4701	1972.7	0.215[illegible]E+03	0.[illegible]E+00	0.661[illegible]E+00	0.5214E+03	15.[illegible]
4901	1918.2	0.211[illegible]E+03	-0.[illegible]E+00	0.727[illegible]E+00	0.5[illegible]E+03	17.[illegible]
4903	1640.4	0.137[illegible]E+03	0.[illegible]E+02	0.[illegible]E+00	0.525[illegible]E+03	15.[illegible]
5001	1903.0	0.[illegible]E+03	-0.[illegible]E+02	0.[illegible]E+01	0.5[illegible]E+03	16.[illegible]
5103	1827.3	0.[illegible]E+03	0.[illegible]E+02	0.[illegible]E+00	0.[illegible]E+03	18.[illegible]
5203	2290.0	0.[illegible]E+03	0.[illegible]E+01	0.[illegible]E+00	0.[illegible]E+03	14.[illegible]
5301	1672.7	0.[illegible]E+03	0.[illegible]E+02	0.[illegible]E+00	0.[illegible]E+03	17.[illegible]
5403	1645.4	0.[illegible]E+03	-0.[illegible]E+01	0.[illegible]E+00	0.[illegible]E+03	17.[illegible]
5503	2317.3	0.[illegible]E+03	-0.[illegible]E+01	0.[illegible]E+00	0.[illegible]E+03	14.[illegible]
5601	1913.6	0.[illegible]E+03	0.[illegible]E+01	0.[illegible]E+00	0.[illegible]E+03	17.[illegible]
5603	2210.0	0.[illegible]E+03	0.[illegible]E+02	0.[illegible]E+00	0.[illegible]E+03	14.[illegible]
5701	2108.2	0.[illegible]E+03	0.[illegible]E+01	0.[illegible]E+00	0.[illegible]E+03	15.[illegible]
5802	1704.1	0.[illegible]E+03	0.[illegible]E+01	0.[illegible]E+00	0.[illegible]E+03	17.[illegible]
6002	2045.4	0.[illegible]E+03	0.[illegible]E+02	0.[illegible]E+00	0.[illegible]E+03	14.[illegible]
6102	2345.4	0.[illegible]E+03	0.[illegible]E+02	0.[illegible]E+00	0.[illegible]E+03	14.[illegible]
6202	1945.4	0.[illegible]E+03	0.[illegible]E+02	0.[illegible]E+00	0.[illegible]E+03	23.[illegible]
[illegible]	1709.1	0.[illegible]E+03	-0.[illegible]E+01	0.[illegible]E+00	0.[illegible]E+03	16.[illegible]
6402	2300.0	0.[illegible]E+03	0.[illegible]E+02	0.[illegible]E+00	0.[illegible]E+03	14.[illegible]
6502	2368.2	0.[illegible]E+03	0.[illegible]E+01	0.[illegible]E+00	0.[illegible]E+03	20.[illegible]
6702	2212.7	0.[illegible]E+03	0.[illegible]E+01	0.[illegible]E+00	0.[illegible]E+03	20.[illegible]
6802	2070.5	0.[illegible]E+03	-0.[illegible]E+01	0.[illegible]E+00	0.[illegible]E+03	18.[illegible]
6902	1845.4	0.[illegible]E+03	0.[illegible]E+02	0.[illegible]E+00	0.[illegible]E+03	16.[illegible]
8101	1750.0	0.[illegible]E+03	-0.[illegible]E+01	0.[illegible]E+00	0.[illegible]E+03	15.[illegible]
8401	2350.0	0.[illegible]E+03	0.[illegible]E+01	0.[illegible]E+00	0.[illegible]E+03	19.[illegible]
8101	1750.0	0.[illegible]E+03	0.[illegible]E+01	0.[illegible]E+00	0.[illegible]E+03	17.[illegible]

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TABLE E
FOUR SMALL HOLE DIAMETER ESTIMATES

[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

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TABLE 2 (CONTINUED)
TWIN SHALL HULL DYNAMOMETER ESTIMATES

ID	DRAYHASS (KG)	FD (KN)	FI (KG/SEC)	FW (KN/M)	FWSQ (KN)	HPSQ (HP)
6507	1613.6	0.73[illegible]E+01	0.70[illegible]E+01	0.25[illegible]E+00	0.30[illegible]E+03	9.[illegible]
6607	1030.0	0.[illegible]E+02	0.[illegible]E+01	0.33[illegible]E+00	0.[illegible]E+03	8.[illegible]
6701	1[illegible]	0.[illegible]E+03	-0.[illegible]E+01	0.[illegible]E+00	0.[illegible]E+03	10.[illegible]
6801	1[illegible]	0.[illegible]E+02	-0.[illegible]E+01	0.[illegible]E+00	0.[illegible]E+03	11.[illegible]
6903	1[illegible]	0.[illegible]E+02	0.[illegible]E+02	0.[illegible]E+00	0.[illegible]E+03	10.[illegible]
5001	1[illegible]	0.[illegible]E+03	-0.[illegible]E+02	0.[illegible]E+01	0.[illegible]E+03	11.[illegible]
5103	1[illegible]	0.[illegible]E+02	0.[illegible]E+02	0.[illegible]E+00	0.[illegible]E+03	13.[illegible]
5203	[illegible]	0.[illegible]E+02	0.[illegible]E+01	0.[illegible]E+00	0.[illegible]E+03	12.[illegible]
5303	1[illegible]	0.[illegible]E+02	0.[illegible]E+02	0.[illegible]E+00	0.[illegible]E+03	12.[illegible]
5403	1[illegible]	0.[illegible]E+01	-0.[illegible]E+01	0.[illegible]E+00	0.[illegible]E+03	11.[illegible]
5503	[illegible]	0.[illegible]E+03	-0.[illegible]E+01	0.[illegible]E+00	0.[illegible]E+03	12.[illegible]
5601	1[illegible]	0.[illegible]E+03	0.[illegible]E+01	0.[illegible]E+00	0.[illegible]E+03	12.[illegible]
5703	[illegible]	-0.[illegible]E+01	0.[illegible]E+02	0.[illegible]E+00	0.[illegible]E+03	12.[illegible]
5801	[illegible]	0.[illegible]E+02	0.[illegible]E+01	0.[illegible]E+00	0.[illegible]E+03	13.[illegible]
5902	1[illegible]	0.[illegible]E+02	0.[illegible]E+01	0.[illegible]E+00	0.[illegible]E+03	12.[illegible]
6002	[illegible]	0.[illegible]E+02	0.[illegible]E+01	0.[illegible]E+00	0.[illegible]E+03	14.[illegible]
6102	[illegible]	-0.[illegible]E+02	0.[illegible]E+02	0.[illegible]E+00	0.[illegible]E+03	13.[illegible]
6202	1[illegible]	-0.[illegible]E+01	0.[illegible]E+02	0.[illegible]E+00	0.[illegible]E+03	12.[illegible]
6302	1[illegible]	0.[illegible]E+02	-0.[illegible]E+01	0.[illegible]E+00	0.[illegible]E+03	11.[illegible]
6402	[illegible]	-0.[illegible]E+02	0.[illegible]E+01	0.[illegible]E+00	0.[illegible]E+03	12.[illegible]
6502	[illegible]	0.[illegible]E+02	0.[illegible]E+01	0.[illegible]E+00	0.[illegible]E+03	13.[illegible]
6602	[illegible]	0.[illegible]E+02	0.[illegible]E+01	0.[illegible]E+00	0.[illegible]E+03	14.[illegible]
6702	[illegible]	0.[illegible]E+03	-0.[illegible]E+02	0.[illegible]E+00	0.[illegible]E+03	13.[illegible]
6802	[illegible]	0.[illegible]E+02	0.[illegible]E+01	0.[illegible]E+00	0.[illegible]E+03	12.[illegible]
6904	1[illegible]	0.[illegible]E+03	-0.[illegible]E+02	0.[illegible]E+00	0.[illegible]E+03	10.[illegible]
5101	[illegible]	0.[illegible]E+02	0.[illegible]E+01	0.[illegible]E+00	0.[illegible]E+03	12.[illegible]
5201	[illegible]	0.[illegible]E+02	0.[illegible]E+01	0.[illegible]E+00	0.[illegible]E+03	12.[illegible]

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TABLE 3
TWIN SHAFT PULL DYNAMOMETER ESTIMATIONS
FOR VEHICLES WITH RADIAL TIRES

ID	WEAVHARS	F0	F1	F2	F=50	HP=50
	(LB)	(LB)	(LB/SEC)	(LB/MPH)	(LB)	(HP)
101	2672.7	0.5301E+02	0.1431E+01	0.5860E+00	0.1035E+03	11.5307
201	1303.6	0.1161E+03	-0.1080E+01	0.4436E+00	0.9615E+02	12.7150
301	1515.6	-0.2134E+02	0.8078E+01	0.2000E+00	0.8271E+02	8.2213
401	1600.0	0.1801E+02	-0.1396E+01	0.2422E+00	0.8215E+02	9.0117
501	1672.7	0.8553E+02	-0.1282E+01	0.2114E+00	0.8276E+02	9.2117
601	1931.8	0.1730E+03	-0.1207E+01	0.4969E+00	0.8780E+02	11.3490
801	1300.0	-0.8702E+02	0.1800E+01	0.1037E+00	0.8331E+02	9.4133
901	2136.3	0.1720E+02	0.5181E+01	0.5058E+00	0.8600E+02	13.1615
1001	1218.2	-0.7726E+02	0.1225E+01	0.6001E+00	0.1026E+03	9.2000
1102	1505.0	0.3201E+02	0.1021E+01	0.4611E+00	0.9374E+02	11.3774
1201	1801.8	-0.9171E+02	0.1431E+01	0.3270E+00	0.8161E+02	10.4713
1301	1827.3	-0.1205E+02	0.1147E+01	0.3216E+00	0.8766E+02	11.3610
1401	1620.9	-0.1404E+02	0.1100E+01	0.2285E+00	0.8578E+02	10.1111
1501	1777.3	-0.1000E+02	0.7100E+01	0.3346E+00	0.8816E+02	9.6027
1601	1506.8	0.7133E+02	-0.1000E+01	0.6493E+00	0.8234E+02	7.6068
1702	1307.6	0.1301E+02	0.1076E+01	0.4734E+00	0.9305E+02	8.4980
1802	1372.7	0.3657E+02	0.1000E+01	0.5944E+00	0.9355E+02	10.1117
1901	1515.6	0.7121E+02	-0.2000E+01	0.5047E+00	0.8586E+02	7.6196
2102	1168.2	0.6711E+02	-0.2071E+00	0.3180E+00	0.8420E+02	8.1761
2201	1615.6	0.1511E+03	-0.1777E+01	0.2477E+00	0.8722E+02	11.2410
2301	2213.6	-0.2100E+01	0.1777E+01	0.5201E+00	0.9274E+02	11.2410
2401	2500.4	0.3207E+02	0.6000E+01	0.5861E+00	0.8661E+02	13.0138
2502	2577.3	0.1530E+03	0.3310E+01	0.3077E+00	0.9348E+02	13.0702
2702	1805.2	0.5127E+02	0.3010E+01	0.3307E+00	0.9241E+02	8.7610
2805	1122.7	0.1350E+02	0.4776E+01	0.3497E+00	0.8241E+02	8.3611
2902	1509.1	0.5127E+02	0.1005E+01	0.3000E+00	0.8241E+02	8.3611
2906	1250.6	0.4830E+02	-0.6977E+01	0.6677E+00	0.8126E+02	7.3611
3011	1231.8	0.1537E+03	-0.6134E+01	0.6946E+00	0.8200E+02	7.5000
3102	1509.1	0.1677E+02	0.5301E+01	0.3577E+00	0.8300E+02	11.3611
3201	1205.6	0.1205E+03	-0.1171E+01	0.2000E+00	0.8411E+02	8.3611
3302	1513.6	0.6325E+01	0.3705E+01	0.3777E+00	0.8411E+02	8.3611
3402	1210.9	-0.5611E+02	0.1000E+01	0.1500E+00	0.8411E+02	8.3611
3502	900.9	0.1000E+01	-0.1071E+01	0.3577E+00	0.8411E+02	10.1100
3611	1063.6	0.1192E+01	0.5301E+01	0.2000E+00	0.8411E+02	10.1100
3702	1205.6	0.3205E+02	0.6000E+01	0.2000E+00	0.8411E+02	8.3611
3803	1210.9	0.6111E+02	-0.1207E+01	0.3577E+00	0.8411E+02	8.3611
3902	900.9	0.9000E+02	-0.3577E+01	0.3577E+00	0.8411E+02	8.3611
4102	2072.7	0.5000E+02	0.6000E+01	0.3577E+00	0.8411E+02	13.0000
4202	2072.7	-0.5000E+02	0.1000E+01	0.3577E+00	0.8411E+02	13.0000
4302	2268.2	0.4000E+01	-0.3577E+01	0.3577E+00	0.8411E+02	13.0000
4402	2072.7	0.5000E+02	-0.1000E+01	0.3577E+00	0.8411E+02	13.0000

TABLE 1 (CONTINUED)
TWIN SMALL HULL DYNAMOMETER ESTIMATIONS
FOR VEHICLES WITH RADIAL TIRES

ID	GRAVMASS (KG)	F0 (LB)	F1 (LB/SEC)	F2 (LB/MPH)	F=50 (LB)	MF=50 (LB)
6501	1413.6	-0.1193E+02	0.7747E+01	0.2515E+00	0.2880E+03	8.6431
6601	1050.0	0.2200E+02	0.2381E+01	0.3350E+00	0.2462E+03	7.2673
6701	1422.7	0.9817E+02	-0.2181E+01	0.5013E+00	0.3340E+03	10.1106
6801	1918.2	0.5962E+02	-0.2545E+01	0.7270E+00	0.4504E+03	13.6417
6901	1650.2	-0.2150E+02	0.1000E+02	0.1701E+00	0.3065E+03	9.1915
5001	1963.6	0.2728E+03	-0.1731E+02	0.1019E+01	0.3692E+03	10.9715
5101	1627.3	0.6921E+02	0.1055E+02	0.2431E+00	0.3048E+03	11.4772
5201	2200.0	0.7191E+02	0.3681E+01	0.6865E+00	0.3625E+03	11.8710
5301	1672.7	0.4851E+02	0.9681E+01	0.2600E+00	0.3424E+03	11.4762
5401	1650.6	0.1422E+03	-0.6221E+01	0.7847E+00	0.3311E+03	11.0801
5501	2307.3	0.8105E+03	-0.1434E+02	0.8120E+00	0.3986E+03	11.8822
5601	1963.6	0.8151E+02	0.3075E+01	0.8280E+00	0.3704E+03	11.3859
5701	2200.0	-0.2324E+02	0.1350E+02	0.2431E+00	0.3048E+03	11.4810
5801	1650.6	0.3032E+02	0.5367E+01	0.6715E+00	0.3622E+03	11.8539
5901	1763.1	0.2026E+02	0.5705E+01	0.6566E+00	0.3771E+03	11.8126
6001	2866.6	0.5042E+02	0.2242E+01	0.3778E+00	0.4660E+03	13.3475
6101	2366.6	-0.3717E+02	0.1615E+02	0.2080E+00	0.4028E+03	12.6612
6201	1926.6	-0.3075E+02	0.1249E+02	0.2566E+00	0.3276E+03	11.4188
6301	1709.1	0.6727E+02	-0.1356E+01	0.7182E+00	0.3535E+03	10.5309
6402	2306.6	-0.6887E+02	0.1243E+02	0.1534E+00	0.3871E+03	11.6003
6502	2306.6	-0.1347E+02	0.6732E+01	0.5551E+00	0.4126E+03	12.6387
6702	2772.7	0.4531E+02	0.2241E+01	0.7456E+00	0.4652E+03	13.6080
6802	2200.0	0.1610E+03	-0.1115E+02	0.9875E+00	0.4191E+03	12.5377
6902	1650.6	-0.6412E+01	0.5605E+01	0.3338E+00	0.3810E+03	11.4936
6101	1750.0	0.1801E+03	-0.1035E+02	0.7656E+00	0.3525E+03	10.7461
6201	2350.0	-0.2707E+01	0.5645E+01	0.5847E+00	0.3942E+03	11.9214
6301	1750.0	0.7218E+02	0.3061E+01	0.4882E+00	0.3815E+03	11.5433

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TABLE 5
SINGLE LARGE ROLL DYNAMOMETER

ID	GRAVMASS (KG)	F0 (NT)	F1 (KG/SEC)	F2 (KG/M)	FWSO (NT)	HPWSO (HP)
101	2072.7	0.13E+03	0.17E+01	0.58E+00	0.47E+03	18.1
201	1983.6	0.24E+03	-0.10E+02	0.99E+00	0.51E+03	13.0
301	1934.6	0.09E+02	0.94E+01	0.20E+00	0.36E+03	11.6
401	1800.0	0.15E+03	-0.46E+01	0.69E+00	0.41E+03	12.2
502	1870.7	0.14E+03	-0.48E+01	0.71E+00	0.39E+03	11.7
601	1931.8	0.22E+03	-0.12E+02	0.96E+00	0.42E+03	12.7
704	1940.0	0.19E+02	0.15E+02	0.10E+00	0.40E+03	12.1
801	2000.0	0.08E+02	0.63E+01	0.65E+00	0.51E+03	15.3
1001	1818.2	0.10E+04	0.87E+01	0.80E+00	0.37E+03	11.1
1102	1900.0	0.09E+02	0.50E+01	0.90E+00	0.42E+03	12.6
1201	1881.8	0.14E+02	0.12E+02	0.32E+00	0.48E+03	14.4
1301	1827.3	0.98E+02	0.10E+01	0.39E+00	0.43E+03	13.0
1401	1890.9	0.40E+02	0.11E+02	0.22E+00	0.41E+03	12.5
1501	1777.3	0.69E+02	0.77E+01	0.35E+00	0.41E+03	12.5
1601	1900.0	0.13E+03	-0.33E+01	0.69E+00	0.30E+03	9.2
1702	1936.4	0.59E+02	0.32E+01	0.43E+00	0.35E+03	10.6
1802	1872.7	0.31E+02	0.37E+01	0.65E+00	0.38E+03	11.4
1901	1890.9	0.13E+03	-0.37E+01	0.56E+00	0.43E+03	9.2
2102	1868.2	0.96E+02	-0.25E+00	0.51E+00	0.34E+03	10.3
2201	1818.2	0.16E+03	-0.50E+01	0.76E+00	0.42E+03	12.8
2301	2213.6	0.28E+02	0.80E+01	0.52E+00	0.66E+03	14.6
2401	2000.0	0.86E+02	0.32E+01	0.69E+00	0.52E+03	15.6
2502	2077.3	0.25E+03	0.30E+01	0.50E+00	0.37E+03	17.1
2602	1990.9	0.80E+02	0.31E+01	0.33E+00	0.29E+03	8.9
2701	1922.7	0.49E+02	0.49E+01	0.36E+00	0.33E+03	10.0
2802	1909.1	0.13E+03	0.12E+01	0.46E+00	0.39E+03	11.8
2901	1936.4	0.11E+03	-0.60E+01	0.68E+00	0.29E+03	8.8
3011	1941.8	0.16E+03	-0.10E+01	0.69E+00	0.38E+03	11.3
3102	1909.1	0.77E+02	0.53E+01	0.37E+00	0.38E+03	11.6
3202	1936.4	0.15E+03	-0.10E+02	0.77E+00	0.30E+03	9.2
3302	1913.6	0.72E+02	0.81E+01	0.47E+00	0.35E+03	10.6
3402	1990.9	0.12E+02	0.17E+02	0.16E+00	0.41E+03	12.6
3503	1886.4	0.13E+03	-0.10E+01	0.52E+00	0.32E+03	10.0
3611	1863.6	0.14E+02	0.98E+01	0.42E+00	0.30E+03	9.1
3712	1936.4	0.66E+02	0.66E+01	0.29E+00	0.35E+03	10.7
3802	1918.2	0.98E+02	-0.10E+01	0.60E+00	0.37E+03	11.1
4015	1990.9	0.12E+03	-0.36E+01	0.68E+00	0.38E+03	11.5
4102	2072.7	0.10E+03	0.81E+01	0.68E+00	0.48E+03	14.5
4202	2077.3	0.36E+02	0.18E+02	0.17E+00	0.59E+03	18.0
4302	2090.9	0.98E+02	-0.32E+02	0.16E+01	0.52E+03	15.8
4402	2004.5	0.16E+03	-0.13E+01	0.66E+00	0.46E+03	13.8

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TABLE 5 (CONTINUED)
SINGLE LAYER HULL DYNAMOMETER

ID	SHAVHASS (KG)	F0 (KG)	F1 (KG/DEG)	F2 (KG/M)	F*SD (KG)	M*SD (KG-M)
[illegible]						